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ENERGY PRICE REFORM WORKSHOP

APRIL 30 - MAY 7, 1992

VILNIUS, LITHUANIA

MAIN WORKBOOK

Presented By:
Resource Management Associates of Madison, Inc.

In Cooperation with:

Tellus Institute
and
Energy Price Reform Working Group
Government of Lithuania

U.S. EMERGENCY ENERGY PROGRAM
United States Agency for International Development
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PREFACE

This Energy Pricing Reform Workshop Notebook is a working document published informally by Resource Management Associates of Madison, Inc. (RMA). To present the results of the project with the least possible delay, this notebook has received only light review, in the interest of timeliness.

This work is being carried out within the framework of the U.S. Emergency Energy program for Eastern and Central Europe under a RMA contract with the U.S. Agency for International Development. RMA, as Prime Contractor to USAID, is currently implementing the **Energy Pricing Reform Project** and the **Industrial Energy Efficiency Project** in Lithuania. The purpose of the Energy Pricing Reform Project is to provide to the Government of Lithuania an analytical basis for understanding energy flows in the Lithuanian economy, underlying costs in the provision and use of energy, major environmental consequences of alternative energy strategies, and other information to support the transition to a market-based pricing system.

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6. MISCELLANEOUS

OUTLINE

ENERGY PRICE REFORM IN LITHUANIA

WORKSHOP

30 April - 7 May, 1992

- 30 April
- 13:00 Introduction of Workshop Topics and Participants
(Hanson and Macezinskiene)
- 14:00 Discussion of Recent Developments in Lithuanian Energy and Environment Situation
(Lithuanian Participant)
- 15:00 Presentation of Lithuanian Energy Balance Evaluation
(Energy Research Institute-Kaunas)
- 16:00 Discussion of Energy Balances
- 1 May
- 9:00 Least-Cost Planning in Market Economies: Market Forces, Market-Based Regulation, and Environmental Costs.
(Hanson and Bartels)
- 10:30 Discussion of Least-Cost Planning Issues in Lithuania
- 13:30 Working Session on Energy Balances
- 15:30 Working Session on Least-Cost Planning Procedures
- 4 May
- 9:00 Electricity and Thermal Tariff Design in Market Economies
(Bartels)
- 11:00 Natural Gas Tariff Design and Transit Fees
(Huddleston)

4 May (cont) 13:30 Discussion of Lithuanian Tariff Structure and Tariff Issues

14:30 Working Session on Tariff Revisions: Fuel Adjustment Clauses, Allowance for Funds Used During Construction, Environmental Costs, and Marginal Cost

5 May 9:00 Macroeconomic Impacts of Energy Price Reform: Concepts and Models
(Huddleston)

10:30 Economic Developments in Lithuania: Input-Output Approaches and Findings
(Lithuanian Participants)

13:30 Discussion of Economic Developments and Model Working Session.

15:30 Working Session: Lithuanian Scenarios

6 May 9:00 Working Sessions:

1. Electricity Tariffs
2. Lithuanian Scenarios
3. Other?

13:30 Working Sessions:

1. Electricity/Thermal Tariffs
2. Lithuanian Scenarios
3. Other?

7 May 9:00 Workshop Summary Discussion: Strategic Pricing Issues

11:00 Next Phase of Project Activities

8 May Follow-up Meetings as Needed

INTRODUCTION TO ENERGY PRICING REFORM

1. WHAT IS A MARKET-BASED PRICE?
 - a. Prices of internationally traded energy commodities
 - b. Prices of non-traded energy commodities
 - c. Prices under natural monopoly
2. DETERMINING MARKET-BASED PRICES
 - a. Free market prices and price reporting
 - b. Use of accounting costs for regulated utilities
 - c. Long-run marginal cost pricing
3. CONSUMER RESPONSE TO MARKET-BASED PRICES
 - a. Firms
 - b. Households
 - c. Service sector
4. MARKET BEHAVIOR AND MACROECONOMIC ISSUES
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 2. Output markets
 3. Natural resources
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 - c. Macroeconomic implications of efficient energy markets
 - d. The use of the industrial, transportation and leap models to represent market

behavior

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- B. Commonality of Problems in Market and Centrally Planned Economies
- C. Monopoly Power and the Regulatory Requirement
- D. Increasing Competition in Regulated Energy Industries under PURPA
 - 1. Private Power
 - 2. Competitive Bidding
- E. Privatization of Public Utilities in Great Britain

II. TRADITIONAL ELECTRIC UTILITY PLANNING

- A. Definitions
- B. Description of Planning Process
 - 1. Parties to the Planning Process
 - 2. Role of Utilities
 - 3. Role of Intervenors
 - 4. Role of Regulators
 - 5. Threshold Criteria
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 - 2. Over-construction by Some Utilities
 - 3. Supply-Side Focus
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I. STRUCTURE OF UTILITY REGULATION IN THE UNITED STATES

A. Predominately Private (Investor Owned) Companies

1. Granted Monopoly Franchises
2. Subject to Direct Regulation At Federal and State Levels

B. Quasi-Judicial Regulatory Body

1. Administrative Versus Legislative Structure

C. Rate Base/Rate of Return Price Regulation

1. Revenues Are Set to Collect Total Cost of Providing Service, Including a Fair Return on Investment (ROI)

$$\text{Rev. Req.} = \text{Expenses} + (\text{Rate Base} * \text{ROI})$$

D. Public Adversarial Process

1. Utility Files Formal Documents in Support of Rate Request
 - a. Estimated Revenue Requirements
 - b. Division of Revenue Requirements Amongst Customer Classes
 - c. Proposed Tariffs
2. Parties Debate Technical and Policy Merits of Proposal Before Commission
 - a. Parties Have Rights of Discovery that Compel Utilities to Provide Information

E. Publicly Owned Utilities

1. Costing and Pricing Practices Often Mimic Private Utility Regulation
2. Sometimes Legislative Versus Administrative Control
3. Infrequent Changes in Mandate Versus Frequent Rate Case Orders

II. CRITERIA FOR SOUND RATE STRUCTURE

A. Classical Considerations

1. Practical
Simple, understandable, publicly acceptable, and feasible regarding application
2. Clear
Freedom from controversies as to proper interpretation
3. Yield Total Revenue Requirements
Expenses and Return on Investment
4. Revenue Stability
5. Rate Stability
Minimize of unexpected changes
6. Fair Among Customers
7. Avoids "Undue Discrimination"
8. Discourages Wasteful Use and Promotes All Justifiable Use of Service
(Promotes Efficient Use of Resources)

Condensed From: James Bonbright, Principles of Public Utility Rates

B. Other Considerations

1. Economic Development
2. Environmental Impacts

III. RATE MAKING PROCESS

A. Cost Based, Not Value Based Rate making

This debate has involved setting the price of public services at the value to the customer or at the cost of the supplier. It has been largely settled in favor of cost based rate making.

B. Three Step Process of Rate Making

1. Determine Revenue Requirement for Company
2. Class Cost Allocation to Customer Classes
(Residential, Commercial, and Industrial)
3. Tariff Design for Each Customer Class

IV. REVENUE REQUIREMENT

A. Purpose

To determine the total revenues required to maintain the utility as a viable entity to ensure the continued provision of public utility service of a desired quality.

B. General Approach

1. Expenses

Estimated for a designated period assuming normal operating conditions

Includes fuel, operation and maintenance, depreciation, insurance, taxes, administration and general, etc.

2. Rate Base

Determined based upon capital dedicated to the public service

3. Return on Investment

Embedded debt cost plus market based return on equity

V. ALLOCATING CLASS REVENUE RESPONSIBILITY

A. General Approach

Zero sum game. Any costs not supported by one customer group are supported by other groups.

Typically Based Upon Fully Distributed, Embedded Costs

Exceptions

- Marginal Cost
- Legislative Mandate (Governmental Agencies Only)

B. Embedded Allocation: Mechanics

Allocation of total revenue requirement amongst customer groups based upon historic causal relationships.

Begins with system of accounts which in the aggregate equal revenue requirements.

1. Functionalization

- a. Purpose: Groups costs according to function to which they relate.
- b. Primary Functions
 - (1) Production
 - (2) Transmission
 - (3) Distribution
 - (4) General

2. Classification

- a. Purpose: Arrangement of functionally grouped costs according to their relationship to measurable cost-defining characteristics of service.

Functional groups can be spread among more than one classification.

- b. Principal Classifications
 - (1) Energy
 - (2) Demand
 - (3) Customer

3. Allocation

- a. Purpose: Selection of particular factors related to classification which allows assignment to particular customer groups.

C. Example: Coal Fired Base Load Generating Station

1. Functionalization: Production
2. Classification: Energy and Demand
3. Allocation: 50% Relative Class Consumption (kWh)
50% Class Contribution to System Peak Demand (kW)

D. Points of Debate in Embedded Allocation

1. Classification and Allocation of Generation Costs Among Demand and Energy
 - a. Fixed vs Variable
 - b. Non-Coincident Peak (NCP)
 - c. Coincident Peak (CP)
 - d. Average and Excess
2. Classification and Allocation of Distribution Costs Among Demand and Customer
 - a. Minimal (or Phantom) System
Customer charges based upon the minimal system necessary to provide voltage but not power; remaining costs allocated based upon NCP
 - b. Minimum Component or Minimum-Intercept Methods
3. Classification and Allocation of Administrative and General Costs

VI. DESIGNING TARIFFS

A. Principal Tasks

1. Determination of Tariff Components
E.g., Customer, Energy, Demand, Power Factor Charges
2. Determination of Structure of Tariff Components
E.g., Block Structures, Ratchets
3. Determination of Price for Each Tariff Component

B. Embedded Cost Tariff Design

1. General Approach

Embedded cost of service study produces unit costs
(e.g., customer, demand, and energy charges).

Structure of tariff (e.g., blocking) and detailed pricing (e.g., pricing of individual blocks) is based upon manipulation of average costs for each component in light characteristics of customer demand.

2. Pros

- a. Cost of components stem directly from allocation of revenue requirements providing total coverage of cost responsibility
- b. Costs are assigned on the basis of the reasons they were incurred

3. Cons

- a. Historic drivers of system development may no longer be related to current uses
- b. May not send correct price signals to consumers

C. Marginal Cost Tariff Design

1. General Approach

A marginal cost study is performed to yield the marginal, (incremental or decremental) costs associated with a marginal (incremental or decremental) change in the number of customers, demand, and energy.

These costs can be related to the individual tariff components; number of customers to customer charge, demand to demand, and energy to energy.

2. Pros

- a. Assigns costs in a forward looking manner to send appropriate price signals to consumers
- b. Pricing may complement resource development
- c. External impacts of electricity use can be incorporated into pricing

3. Cons

- a. Not Tied to Utility Accounts
 - (1) Ideal prices may not generate desired revenue requirements
 - (2) Requires projection of incremental costs

4. Principal Issues

- a. Sufficiency of Period Analyzed
Long-Term Avoided Costs versus Short-term Marginal Costs
- b. Determination of Marginal Costs
To Meet Incremental Consumer Demands
 - (1) Customer
 - (2) Demand
 - (3) Energy
- c. Fulfilling Revenue Requirements
 - (1) Potential over-collection requires decreasing at least one component below marginal cost
 - (2) Potential under-collection requires increasing at least one component above marginal cost

- D. Points of Debate in Tariff Design**
Common to Embedded and Marginal Approaches
- 1. Blocks or Their Equivalent in Rate Design**
 - 2. Determination of Pricing Periods**
Seasonal, Weekly, Daily
 - 3. Whether to recognize External Impacts on Society**
 - a. Environmental Damage**
 - b. Economic Development**

VII. BASIC INFORMATION REQUIREMENTS

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 - a. Contribution to System Coincident Peak
 - b. Contribution to Class Coincident Peak
 - c. Non-Coincident Peak (Customer Peak)
2. Elasticity of Customer Demands

B. Accounting Information

1. Utility Accounts Suitable for Functionalization and Classification
2. Embedded Cost of Service Study

C. Planning Studies

1. Marginal Cost
2. Long-Term Avoided Costs
3. Stress Factor Analysis

USER'S GUIDE TO THE INDUSTRIAL SECTOR ENERGY DEMAND MODEL

**LITHUANIA ENERGY PRICE REFORM PROJECT
USAID EMERGENCY ENERGY PROGRAM
FOR EASTERN AND CENTRAL EUROPE**

(USAID CONTRACT #: EUR-0015-C-00-1006-00)
April 1992



RESOURCE MANAGEMENT ASSOCIATES
of Madison, Inc.

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Conceptual Design (Structural Changes in Industrial Energy Use)

Appendix B

Operational Description: Parameter Specification

Appendix C

Incorporation of Time Lags in the Industrial Model

1.0 Introduction

The RMA Industrial, Agricultural and Construction Sector Energy Demand Model (Industrial Model for short) provides a structure for estimating the effects of changing energy prices on the quantity of energy consumed and the output growth of distinct industrial subsectors and the agricultural and construction sectors. The Industrial Model divides the Lithuanian Industrial, Agricultural and Construction (IAC) sectors in 9 subsectors and models them over a base year and 5 future years.

The model is intended as a tool to explore the impacts of various policy options facing Lithuania, upon the energy demand and economic health of the IAC (industrial, agricultural and construction) sectors. The policy options are represented in the Industrial Model by sets of assumptions (or scenarios) regarding exogenous growth rates of each IAC subsector, as well as policy choices in areas such as energy prices.

The Industrial Model determines industrial energy use and output over five future years. Of particular interest are changes in the output, energy mix and energy intensity of each IAC subsector. An overview (or time path) of the IAC sectors adaptation to energy policy changes are presented in numerical tables and graphic charts.

The user must enter a set of energy consumption, and social product (in Rubles) for each subsector in the base year, the desired modeling periods, expected underlying subsector growth rates and energy price changes for the modeling periods, and two types of fuel price elasticities. The elasticities are specified for *each subsector-fuel pair* in the analysis; they are the fuel price elasticity of energy demand and the energy price elasticity of industrial output.

The underlying subsector growth/decline rates in the model represent how IAC subsectors will grow/decline in the *absence* of energy price changes. In order to negate the effects of inflation over the modeling horizon, the *real* (adjusted for overall inflation) energy prices for each future year are required. Energy prices and the value of IAC output should be in *constant* rubles. It would probably be easiest to set all future year prices in base year (1990) rubles

For each future year, the output of each IAC subsector is calculated based on a function of the fuel mix, underlying economic growth forecast, fuel price, and the output elasticities. The expected energy consumption for each subsector and fuel type is then calculated based on a function of fuel prices, demand elasticities and the energy consumption in the previous time period. Changes in energy intensity (the ratio of fuel consumption to subsector output) are also determined by the model.

This User's Guide is organized as follows. Section two briefly discusses the conceptual design and purpose of the model. Section three presents the model's overall structure and outlines the contents of each component of the model. Section four reviews how to protect and unprotect portions of the model from being altered. Section five, a step-by step guide to model operation and relevant Quattro Pro® commands, is likely to be of most interest to a Quattro Pro® novice. Section six covers the Comparison File which allows the user to compare two scenario runs. Section seven discusses the equations which are imbedded within the model.

2.0 Conceptual Design

The driving variables in this model are the underlying IAC (industrial, agricultural and construction) sector growth rates and changes in energy prices over the selected set of future years. When these changes are part of an upward energy price adjustment policy, each round of price increases constitutes an energy "shock" to the economy, and initiates substitution of higher priced fuels with lower priced fuels or factor inputs (e.g., labor and/or capital).

The Industrial Model links fuel and factor input substitutions caused by energy price changes by using two types elasticities. One elasticity (the energy price elasticity of demand) relates changes in energy demand in each subsector caused by energy price changes. In a climate of escalating energy prices energy users will tend to adjust their input mix by decreasing reliance on energy through the substitution of other factor inputs. The other type of elasticity (the energy price elasticity of output) relates the changes in subsector growth as to variations in fuel prices. It is expected that as energy prices increase, production cost and final price is driven up and therefore the demand for products falls. In an environment of escalating fuel prices, the output of energy-intensive subsectors will be severely affected. A more detailed discussion of the conceptual design of the model and structural changes in IAC energy use are given in Appendix A.

3.0 Implementation and Specification

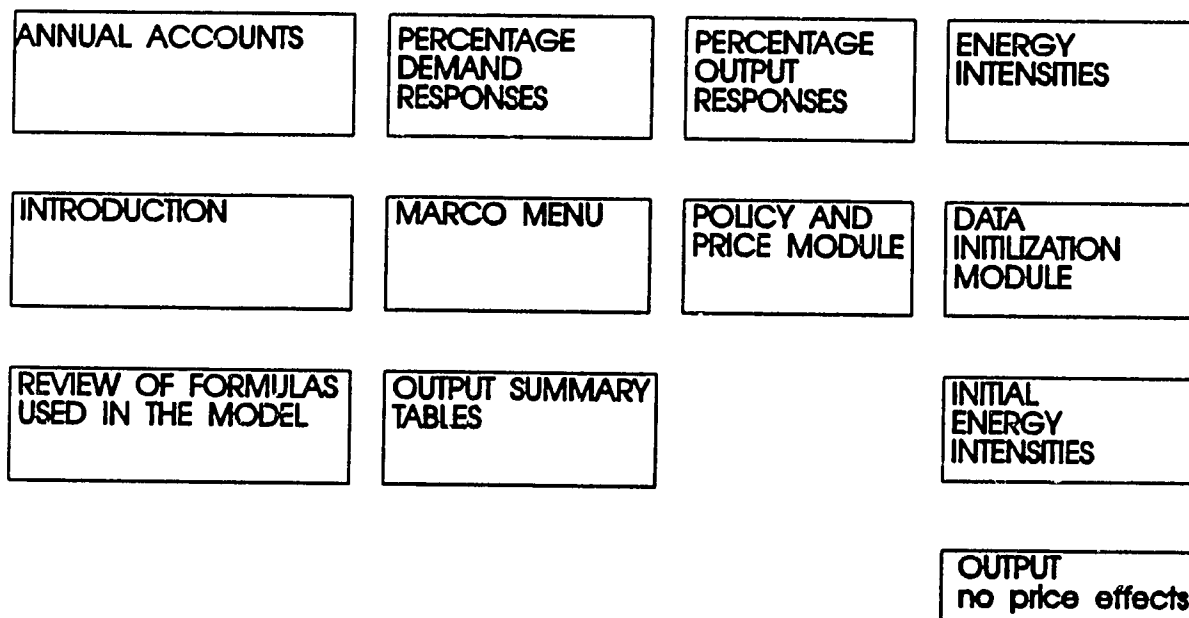
3.1 General Model Structure

The model is implemented in the Quattro-Pro®/(©Copyright, Version 2.0 1990 Borland International) spreadsheet software program. The arrangement of the modules within the Industrial Model is shown in *Figure 1*. The first module that the user will view is a brief introductory note on the content and development of the model. By pressing the *Alt and M* keys simultaneously, the user can go to the macro menu from any part of the model. This lists a number of macros (small internal programs) which are executed by other *Alt* and letter key combinations (see *Table 1* for list of macro commands). Some macros move the user to the requested module. For example, pressing the *Alt and D* keys simultaneously moves the cursor to the top left hand corner of the Data Initialization Module. Other macros print desired worksheets (currently the macro print commands will operate only on laser or bubble jet printers) or generate and display graphs of particular results.

Table 1: Macro Menu

KEY SEQUENCE	FUNCTION or RESULT
Alt-M	Go to Macro Menu
Alt-I	Go to Pricing/Policy Input Module.
Alt-D	Go to Data Initialization Module
Alt-T	Go to Summary Tables
Alt-W	Go to Main Worksheet of Model
Alt-S	Save Model with Changes
Alt-O	Auto exec to Model Introduction
Alt-N	Print Main Worksheet
Alt-A	Print Data Initialization
Alt-B	Print Pricing/Policy Input
Alt-C	Print Yearly Energy Intensity Accounts
Alt-P	Print Summary Tables
Alt-G	Graph of IAC Social Product (IAC SP) by subsector and year
Alt-F	Graph of Energy Use by Fuel Type
Alt-E	Graph of Energy Use by Subsector
Alt-X	Graph of Energy Intensity by Subsector
Alt-R	Graph of Annual IAC SP growth by Subsector
Alt-L	Graph of Percentage Fuel Price Changes
Alt-H	Print Graph of IAC Social Product
Alt-J	Print Energy Fuel Graph
Alt-K	Print Energy Sector Graph
Alt-Q	Print Energy Intensity Graph
Alt-Y	Print Growth Rate Graph

Figure 1. Spatial Arrangements of Worksheets Within the Industrial Model



Sections 3.2 - 3.6 describe each module in the order suggested for first-time users. The user should begin by accessing the Data Initialization Module and then progress step by step through the remaining modules to the Summary Tables Module.

3.2 Data Initialization Module

The data initialization module contains the initial data set for the analysis. Listed below are the types of information that need to be entered and the cell reference:

CELL	DESCRIPTION
AB122	A title, 18 characters or less
W126 & Y-AC126	Base year and the five future years for analysis. This model uses 1990 as the base year and projects energy demand in 1992, 1994, 1996, 1998 and 2000.
X153-161	Base year output in monetary units by IAC (industrial, agricultural and construction) subsectors.
Z153-AD161	Exogenous underlying growth forecasts for each IAC subsector and each future year.
X132-AD140	Base year energy use by IAC subsector and fuel type. This can be entered in the typical physical units (e.g., Tons of Coal).
X148-AD148	Base year prices for fuels. If the user wishes to enter relative price changes without entering actual prices, this can be done by entering a 1 for each base year price and then entering price changes as fractions.
X172-AD173	Conversion and scale factors for fuels which are used to change fuel in physical units to Terajoules.

3.3 Policy/Price Module

The policy/price module is a parameter set related to prices and policy choices. Three types of parameters are needed:

CELL	DESCRIPTION
P129-V133	Real prices in constant base-year dollars for fuels, or price changes expressed as multiple of base year price.
P139-V147	Price elasticities of demand (energy price response), by IAC subsector and fuel type. The elasticity values are likely to range from 0 to -1.

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P153-V161 Price elasticities of output (output price response), by IAC subsector and fuel type. The elasticities are likely to range from 0 to -2.

3.4 Main Worksheet

The main worksheet module consists of three components: Annual Accounts, Percentage Demand Responses, and Percentage Output Responses.

- (1) **Annual Accounts:** Contains a yearly accounting by IAC subsector of the value of output (e.g., millions of Rubles) and energy use by fuel type in TJ (terajoules), beginning with the base year input data. It also includes annualized growth rates, energy use fractions by subsector and fuel type, percentage changes from one period to the next, and yearly totals for energy use. (The print macro for 'Main Worksheet' prints only the annual accounts.)
 - (2) **Energy Demand Adjustment Factors:** Energy demand adjustment factors are calculated, by fuel and IAC subsector for each future year of the analysis, from previous fuel price changes and price elasticities of energy demand. They represent the fractional change in energy use from the previous period. The calculation of this response is given in section 7.1.
 - (3) **Output Adjustment Factors:** Output (Social Product) growth adjustment factors are calculated, by fuel and industrial subsector for each future year of the analysis, from fuel price changes and price elasticities of energy output. A given value represents the fractional change in energy use from the previous period for each IAC subsector attributable to price changes for a particular fuel. This is further discussed in section 7.2.
- 3.5 **Energy Intensity:** The energy intensity table lists the energy intensities for the base year and future years, for each fuel type and each IAC subsector. For any given year, the energy intensity is equal to the calculated energy use divided by the adjusted output for a given subsector.
- 3.6 **Summary Tables:** The summary tables contain annual summary calculations. Graphs and data are displayed and printed by using the macro menu. This worksheet contains:

- (1) Total energy use by industrial subsector.
- (2) Total energy use by fuel type.
- (3) Growth rate by IAC (industrial, agricultural and construction) subsector.
- (4) Energy intensity by IAC subsector.
- (5) Percentage changes in fuel prices over entire period.
- (6) Percentage shares of IAC output (social product) for each subsector.
- (7) Percentage shares of energy use for each subsector.
- (8) IAC Social Product for each subsector in Million of Rubles.
- (9) The model may also be used to supply data for the LEAP Model (Tellus Institute, 1991).

The LEAP (Long-range Energy Alternatives Planning) model "is a computer-based accounting and simulation tool designed to assist policy makers in evaluating energy policies and developing sound sustainable energy plans". A set of aggregated data from the Industrial Model has been formatted to facilitate data transfer into the LEAP model.

4.0 Protection of Cells

A large number of cells are protected to prevent the user from accidentally replacing key portions of the model. If the user is comfortable with Quattro Pro and the model, a group of cells can be "unprotected" so that the contents of cells can be changed. To unprotect a portion of the spreadsheet, type */SP* to activate the **STYLE** menu and the **PROTECTION** sub-menu. The computer will now ask you to select the cells that you wish to unprotect. The location of the cell the cursor was in before typing */S*, will appear at the top of the screen (e.g., A10..A10). If this is the only cell you want to unprotect, press *"Enter"* and the computer will highlight that cell. Otherwise move the cursor, using the arrows keys, to highlight the block of cells you wish to unprotect and press *"Enter"*. If you would like to highlight cells that do not include the cell the cursor is currently in, press *Esc* and move to the cell which would be the top left corner of the block and strike the period (.) key. The period key anchors the block. Then select the size of the block with the arrow keys, as described before, and press *"Enter"*. The cells are then unprotected and the user may enter new data.

To unprotect the entire spreadsheet, type */O* to activate the **OPTIONS** menu and type *P* to select **PROTECTION**. Change this from **ENABLE** to **DISABLE** then type *Q* to quit the **OPTIONS** menu.

5.0 Operating the Model

An example is given below to illustrate the basic principles of the Quattro-Pro® spreadsheet program and the Industrial Model. For more advanced procedures the reader/user is referred to the Quattro-Pro® 2.0 User's Guide. (©Copyright 1990, Borland International, Inc.). The following steps should be taken by an inexperienced Quattro Pro and Industrial Model user for proper operation of the model. The appropriate keystrokes and resultant action are given.

1. **Open Quattro Pro® Program.**
2. **Opening Files -** Type */FR* (file, retrieve). This command opens the "File pull down menu" at the top of the screen and a message appears "Open File C:\QPRO" with a list of files below. If the model file is on the hard drive C:, move the cursor with the arrow keys to the file name (e.g., ISCENA (industrial model scenario A)) and press *Enter*. If the file is on a floppy disk, for example the B: directory, press "*Esc*" twice and type in the directory name (A: or B:), press "*Enter*" and when file names in the directory appear, move the cursor to the desired file (e.g., ISCENA) and press "*Enter*".
3. **Opening a Second File -** If the user wishes to open a second spreadsheet while the primary file (ISCENA) remains active, type */FO* (file, open) and then call up the second spreadsheet, as described above. If the user wishes to replace the active file ISCENA with the second spreadsheet, type */FR* (file, retrieve) and then pick the file you wish to access. The "replace" command will overwrite the primary spreadsheet
4. **The Multiple Industrial Energy Demand Scenarios -** Multiple Industrial Model scenarios can be modeled, each with its own file name (e.g., ISCENB, industrial model scenario B). The user may choose to open multiple scenarios at a time. Simply follow the commands outlined above in step three and pick the scenario file you wish to access.
5. **Screen Presentations of Multiple Files and Moving Between Active Files -** When multiple spreadsheet are active two screen presentations are possible; the files may either be "Stacked" or "Tiled". Stacked files are layered one file on another. The tiled option allows the user to view portions of all files simultaneously. To stack files type */WS* (window, stack)). To tile files type */WT* (window, tile). Then to move between files type */WP* (window, pick) and choose the file name which you wish to activate and press "*Enter*".

7. **Moving Between Modules** - Each spreadsheet is composed of 12 worksheets (see *Figure 1*). To move between worksheets use the macro commands or use the arrows keys. By typing "*Alt-M*" the cursor will move to the Macro Menu. Type the Macro command of the desired module, such as, "*Alt-I*" and cursor moves to the upper left hand corner of the Pricing Input Module. Fuel prices may then be entered or changed. Other modules can be reached and updated in a similar manner.
6. **Entering Data and Updating Scenarios** - To enter or change base year energy consumption or output, use the arrow key to move to the desired cell (see section 3.2). Type the number that you want to have in that cell and press "*Enter*" and the previously displayed value will be replaced.

At this point, the computer may refuse to change the number and send you an error message. This may occur if the cells have been protected. To determine if the cell has been protected inspect the value of the cell displayed at the top left-hand corner of the screen. If the letters "PR" appear before the numeric value then the cell is protected. Most of the cells in the spreadsheet are protected to prevent the user from accidentally replacing an entry. The protection of cells and procedures to unprotect cells are explained in section 4.0.

8. **Recalculating** - Once all data changes have been made to the model it is necessary to recalculate the model. This is done by pressing *the "F9" key* (the recalculate key). The recalculate key will recompute all formulas within the spreadsheet file using the latest data. The *F9 key* should be used whenever the letters "CALC" (calculate) appear at the bottom center of the screen, since the calculations are only done if the user gives the command. The computer will give a "Wait" message while it is calculating and a "Ready" message when it is completed.
9. **Summary Results** - To view the Summary Tables of a scenario run type "*Alt-T*". Other *macro* commands (to see the macro menu type "*Alt-M*") will display a number of graphical representations of these summary tables. To exit from a graph, press any key and then press "*Q*" for Quit.
10. **Saving a File** - If you would like to save the changes you have made, you need to save the scenario under a file name. Type */F* to open the **FILE** menu. Select **Save** from the **FILE** menu. The computer will flash a message that says file already exists (the file name is at the bottom of the spreadsheet) and asks you to indicate whether you want to "**Cancel, Replace or Backup**" the file. Use the arrow keys to highlight **Replace** and press *Enter* or simply press *R*. This will **Replace** the old file (e.g., ISCENB) with the new file recently updated scenario. The updated scenario will be written over the older file;

resulting in the deletion of the older scenario. Selecting **Cancel** will exit the user from this menu and the newly updated scenario will be lost.

If you would like to keep the old scenario (e.g., ISCENB), then save your new file under a different name. To do this select "Save As" from the **FILE** menu by typing */FA*. The computer will indicate the current file name ISCENB. Choose a new name for the revised file, press "*Esc*" and type in the new name (e.g., ISCENC). The revised version is now saved under a new name and the original file still exists.

11. **Exiting** - To exit the spreadsheet file type */F* to open the **File** menu. Move the cursor the "Close" and press "*Enter*" (or type "C"), this will either Exit your file or a message will appear "Lose your Changes?". If you wish to save your changes select "No" and follow the steps in #10 above. If you do not wish to save your changes select "Yes" and the file will close. To exit the spreadsheet type */FX*.
12. **The "Esc" Key** - The "*Esc*" key is used to exit from any Quattro Pro® menu choice. For example if you accidentally typed ISCENB when asked for the name of the file to be saved but you did not want to replace the existing file, just press "*Esc*" and the name will be erased. If you are not sure where you are during any procedure, pressing "*Esc*" a number of times will get you back into the spreadsheet.

6.0 Comparison File

Summary tables from two different scenarios can be compared in the Quattro-Pro® file called COMPARE. *Figure 2* shows the spacial arrangement of the worksheets within the COMPARE file. The entire file is protected from being changed by the user. If any changes are desired, these should be done in the scenario files and not in the comparison file. The COMPARE file compiles the results from two different scenario runs (each saved under different file names (e.g., ISCEN1 and ISCEN2)) and uses six graphs to compare their results. The graphs compare: Total Energy Use, Overall Energy Intensity, Energy Use by Fuel Type, IAC Social Product, Subsector Energy Intensity and Total IAC Social Product.

Equations in the cells of the COMPARE file refer to cells within two other spreadsheet files (say ISCEN1 and ISCEN2), by referring first to the file name and then the cell within that file (e.g., [ISCEN1]AB126). This referencing of other files is called "linking".

If the user wishes to compare modeling runs different than those currently built into the COMPARE file (e.g., ISCEN1 and/or ISCEN2) the links to those spreadsheet files can be changed. The links are changed from within the COMPARE file. To change the files being compared type; \TUC (tools, update links, change), pick the spreadsheet name you wish to change (e.g., ISCEN1), strike *Enter*, type in the name of the new spreadsheet (e.g., ISCEN3), strike *Enter* and repeat if you wish to change the name of the spreadsheet file to be compared.

Each time the comparison file is opened, the computer will ask the user to: (a) "Load supporting" (files), (b) "Update refs" (references) or (c) None. Option (a) opens all supporting (or linked) files while option (b) updates the cell links and option (c) replaces all linked values with NA (not available) comments. Option (b) will usually suffice. Option (a) should be used when the user wishes to see all linked files, but due to memory limitations this will often be impossible.

A number of tables and graphs for the visual comparison of the two scenarios are built into the COMPARE file. The graphs are accessed using macro commands listed in the macro menu. Type "Alt-M" to view the macro menu (*table 2*).

Table 2: Macro Menu for the Comparison File

KEY SEQUENCE	FUNCTION or RESULT
ALT-M	Return to menu
ALT-E	Graph Total Energy Consumption
ALT-I	Graph Energy Intensity
ALT-F	Graph of Energy Consumption Across Fuel Types
ALT-G	Graph Economic Growth
ALT-H	Graph of Subsector Energy Intensities
ALT-P	Graph IAC Social Product

Figure 2. Spatial Distribution of Worksheets Within the COMPARE File

SCENARIO A

INDUSTRIAL FUEL USE
BY SUBSECTOR

INDUSTRIAL USE
BY FUEL TYPE

GROWTH RATE
BY SUBSECTOR

ENERGY INTENSITY
BY SUBSECTOR

PERCENTAGE PRICE
INCREASE OF FUELS

PERCENTAGE SHARE
OF INDUSTRIAL OUTPUT

PERCENTAGE SHARE
OF ENERGY USE

GROSS INDUSTRIAL
PRODUCT

LEAP INPUTS

INTRODUCTORY
STATEMENT

MACROS

SCENARIO B

INDUSTRIAL FUEL USE
BY SUBSECTOR

INDUSTRIAL USE
BY FUEL TYPE

GROWTH RATE
BY SUBSECTOR

ENERGY INTENSITY
BY SUBSECTOR

PERCENTAGE PRICE
INCREASE OF FUELS

PERCENTAGE SHARE
OF INDUSTRIAL OUTPUT

PERCENTAGE SHARE
OF ENERGY USE

GROSS INDUSTRIAL
PRODUCT

LEAP INPUTS

7.0 Calculation Procedures

7.1 Energy Demand Adjustment Factor (AF_q)

A major concern of energy pricing policy and the Industrial Model is the relationship between the price p of a fuel and demand q for a fuel in each IAC subsector. IAC consumers of the fuel in a competitive economy are assumed to behave consistently over time in response to price changes of the fuel. Specifically, IAC consumers are expected to respond to a percentage change in the price with some proportional change in demand. Let this constant of proportionality be ϵ (elasticity), so that $\epsilon = (dq/q)/(dp/p)$. If (p_1, q_1) is an initial price-demand equilibrium and (p_2, q_2) is a new price-demand equilibrium after some time period i , then we have:

$$\int_{q_1}^{q_2} \left(\frac{dq}{q} \right) = \int_{p_1}^{p_2} \epsilon \times \left(\frac{dp}{p} \right) \quad (1)$$

When ϵ , p_1 , q_1 , and p_2 are given, q_2 can be calculated. Equation (1) can be solved and expressed as:

$$q_2 = q_1 \times \left(\frac{p_2}{p_1} \right)^\epsilon \quad (2)$$

The assumption of constant elasticity results in an exponential function parametrized by ϵ , or equivalently, a proportional relationship between the log functions of price and demand. Equation (2) permits the demand for a given fuel in a particular IAC subsector to be calculated for a given period as a function of the fuel demanded in the previous period, the price ratio and the price elasticity.

In the Industrial Model, q_1 is set to equal 1 and the value q_2/g_1 is set to equal AFq_2 . AFq_2 is the "energy demand adjustment factor" at time 2. It measures the change in the quantity of fuel demanded due to changes in price at time 2 **relative** to the quantity demanded at time 1.

$$AFq_2 = \frac{q_2}{q_1} = \left(\frac{p_2}{p_1} \right)^\epsilon \quad (3)$$

7.2 Output Adjustment Factor (AFy)

A relationship for price p and output y can be established in an analogous way to the relationship established for price and energy demand. By replacing quantity demanded q with output y , equations (1) and (2) can be used. However, an important modification must be made. No longer can the relationship be expressed one fuel at a time. Instead, the fuel mix must be accounted for in the functional relationship for output and prices. Thus, we must define a new function the fuel fraction. A subsector's fuel fraction at time 1 for fuel type j (ff_{j1}) is simply the energy consumption use of fuel type j (f_{j1}) divided by the subsectors total fuel use at time 1 (f_{t1}) or:

$$ff_{j1} = \frac{f_{j1}}{f_{t1}} \quad (4)$$

The initial and final prices of fuel type j (p_{j1} and p_{j2}) and the price elasticity of output (ϵ_j) for fuel j are also needed. Given a subsector's initial consumption of fuel j (y_{j1}), then the adjusted equilibrium output (y_{j2}) can be expressed as:

$$y_{j2} = y_{j1} \times ff_{j1} \times \left(\frac{p_{j2}}{p_{j1}} \right)^{\epsilon_j} \quad (5)$$

In the Industrial Model, y_{j1} is set to equal 1 and the value y_{j2}/y_{j1} is called a "output adjustment factor" (AFy_{j2}). The output adjustment factor reflects the change in a subsector's output due to changes in price for fuel j at time 2, **relative** changes in output at time 1. Equation (6) is the method by which a subsector's price elasticity of output is determined for **each** fuel type.

$$AFy_{j2} = \frac{y_{j2}}{y_{j1}} = ff_{j1} \times \left(\frac{p_{j2}}{p_{j1}} \right)^{\epsilon_j} \quad (6)$$

The output adjustment factor for all fuel types used by the subsector is then calculated by summing the output adjustment factors for each fuel type.

$$AFY_2 = \sum_{j=1}^J AFy_{j2} \quad (7)$$

Equations (4)-(7) follow the step-wise calculation process used within the Industrial Model. These four equations can be combined into one, perhaps more intuitive, equation:

$$Y_2 = Y_1 \times \sum_{j=1}^J [ff_{j1} \times \left(\frac{p_{j2}}{p_{j1}} \right)^{\epsilon_j}] \quad (8)$$

The elasticity equations (3) and (6) assume that the output and energy demand responses occur "instantaneously" as fuel prices change. In the real world these responses usually occur over longer time scales (months or years). In other words, the IAC sector will gradually adjust its energy demand and output rather than responding immediately to price fluctuations. Although the current form of the model does not address time-lagged effects, a discussion of how to incorporate lags is discussed in Appendix C.

7.3 Growth in Industrial Output (Social Product)

The analysis considered here is from the perspective of a *partial* equilibrium. The effects of changing energy prices are considered with the assumption that other prices in the economy remain constant. Yet the output of the economy will change as a result of the changing price-demand-supply patterns of the rest of the economy. Thus, one of the required types of information for this analysis are *exogenous* projections of underlying growth rates for output in each IAC subsector under the assumption of constant real energy prices.

If y_1 is output for a given subsector in period i , AFy_2 is the output adjustment factor for time 2, r_i is the exogenously determined growth rate for period i (time 1 to time 2), and t is the length in years of period i , the resulting output y_2 is:

$$y_2 = y_1 \times AFy_2 \times (1+r_i)^t \quad (9)$$

7.4 Energy Use Calculations

Energy demand by fuel and subsector is calculated using the previous period's energy use by fuel and subsector (X_1), the energy demand adjustment factor for the current year (AFQ_2), the number of years in period i (t), and the adjusted growth rate of the subsector over period i (R_I). First, the adjusted growth rate must be calculated.

$$R_I = \left(\frac{y_2}{y_1} \right)^t - 1 \quad (10)$$

Equation (11) is then used to determine energy demand by fuel type and subsector at time 2.

$$X_2 = AFQ_2 \times X_1 \times (1+R_I)^t \quad (11)$$

Note, that energy consumption data is calculated **after** IAC output is adjusted for energy price fluctuations. This allows for the expected current-period growth to be figured into the determination of energy consumption. The calculation of the energy use matrix is sequential, with each period's results derived from the energy use matrix of the previous period. Together with the adjusted output values, the energy use data sets can be used to calculate the energy intensity and fuel fraction.

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APPENDIX A
Conceptual Design (Structural Changes in Industrial Energy Use)

During the transition to market economies, energy use patterns will undergo a variety of structural changes. The aggregate effect of these changes is expected to be a decrease in the energy intensity of produced goods. Four types of structural changes are envisioned in IAC sector energy use: fuel substitution, intersectoral substitution, intrasectoral changes in technological processes, and increased value of goods produced. In practice, it is difficult to separate and identify these changes without careful analysis of detailed historical data on energy use and economic activity. However, the IAC Sector Energy Demand Model offers a conceptual structure with which to explore general trends and response characteristics of energy price changes for a set of subsectors and fuel types.

Substitution effects in energy use are a direct consequence of the interchangeability of fuels in a particular application. The "own-price" elasticity of a fuel is a measure of responsiveness of demand to changes in fuel price. For example, an elasticity of (-2) indicates that when the price of the fuel goes up by 1%, demand goes down by 2%. The "cross-price" elasticity provides the analogous measure of responsiveness of demand for a fuel to the changes in price of a *different* fuel. If two fuels are substitutable, their cross price elasticities will be positive because firms will substitute the lower cost fuel in response to a price change. The elasticity, in a sense, indicates the ease with which such substitution could be made. Negative cross-price elasticity indicates that the fuels are complementary, meaning that some IAC activities require both fuels for production, perhaps in a fixed proportion. Cross price elasticities are not considered within the Industrial Model.

Intersectoral changes include those responses to energy price changes for which the allocation of output shifts among sectors so as to reduce energy use. Intersectoral changes will increase output of one sector by lowering energy use and/or output of another sector, in a relative sense. As energy prices increase, output will gravitate towards those sectors which are less energy intensive. It is likely that intersectoral shifts depend on the aforementioned capability for fuel substitution. Sectors which depend greatly on one fuel will obviously be disproportionately affected by some price changes. However, there are a host of other factors, such as labor, capital mobility and access to import/export markets, which also affect intersectoral changes and thus must be considered.

Changes in technological processes are more intrasectoral than intersectoral. The industrial sector responds to rising energy prices with more energy efficient equipment and processes. Specific production features are altered and processes redefined to meet the changing energy price structure. Investments are made to implement the changes by purchasing and/or developing new equipment, perhaps stimulating the creation of another industry in the process. Examples might be the adoption of continuous casting in a steel mill or a more precise temperature controller for an industrial process. Some of these changes may require considerable time for implementation, which is sometimes accounted for by distinguishing between short-term and long-term elasticities. The short-term elasticities attempt to account for "housekeeping" measures to improve energy efficiency while long-term elasticities attempt to account for the more difficult but substantial technological improvements. Short and long-term elasticities are not incorporated into the RMA Industrial Model rather all adjustments are modeled to occur instantaneously.

The short-term growth of particular subsectors will be affected by the increased costs producers face for energy inputs. As discussed above, one result will be intersectoral shifts in production to less energy-intensive subsectors. However, rising energy prices will be accompanied by other price changes in the economy. At the same time, the rising energy prices have stimulated technological innovations to use energy more judiciously. As a result, the goods and services produced in the restructured economy are enhanced in value because they require fewer inputs. Furthermore, the price mechanism allows the energy inputs to gravitate to those users who value them the most in their production processes. Savings in energy costs will permit further investment and the economy will begin to grow again, but this time less dependent on energy inputs. At some point in this cycle, we can expect some of these transitional effects to taper off, and further improvements in energy efficiency will require increasing effort. At this point, the Lithuanian economy will be approaching the economic structure and energy efficiency typical of the Industrialized Market Economies.

The model attempts to capture these structural changes through an energy use matrix along with related data and parameters. It should be recognized that there exists a great deal of uncertainty in the actual responses to price changes. However, this model is strictly deterministic in nature. There is no explicit incorporation of stochastic variables as a means of capturing such uncertainties. This means that the changes in energy use patterns are best interpreted in a relative sense, from one scenario to another, rather than attributing importance to specific numerical estimates. The usefulness of the model for policy analysis thus comes from the structure it provides for conceptualizing the various relationships between energy prices and IAC energy use patterns.

APPENDIX B
Operational Description: Parameter Specification

a. Initial Energy and Output Data

Assume that there are n fuels in the economy f_j , $j = 1, \dots, n$ and m subsectors of industrial production s_i , $i = 1, \dots, m$. The initial data for the fuels and sectors includes an $m \times n$ matrix of the energy used for each fuel in each sector, x_{ij} in various energy units and an $m \times 1$ vector of the y_i , the value-added or IAC Output for each sector i :

	f_1	f_2	.....	f_n	
s_1	x_{11}	x_{12}	.....	x_{1n}	y_1
s_2	x_{21}	x_{22}	.....	x_{2n}	y_2
\downarrow	\downarrow	\downarrow		\downarrow	\downarrow
s_m	x_{m1}	x_{m2}	.....	x_{mn}	y_m

The energy data is converted to common units of Terajoules to permit aggregation and comparisons across subsectors and fuel types.

b. Price Elasticities

Price elasticities measure the responsiveness of other variables to changes in price. As described in Section 6.0, two types of elasticities must be specified: price elasticity of energy demand and price elasticity of output. Both must be specified for each fuel-subsector pair, resulting in two matrices of identical dimensions to the energy use matrix, $(m \times n)$, where ϵ_{ij} is the elasticity for subsector i and fuel j :

	f_1	f_2	.....	f_n	
s_1	ϵ_{11}	ϵ_{12}	.....	ϵ_{1n}	
s_2	ϵ_{21}	ϵ_{22}	.....	ϵ_{2n}	
\downarrow	\downarrow	\downarrow		\downarrow	
s_m	ϵ_{m1}	ϵ_{m2}	.....	ϵ_{mn}	

Elasticities of fuels, as with most goods, tend to be higher in the long-run than in the short-run. Our analysis will be confined to ten-year scenarios. For longer-term analyses, it may be desirable to incorporate changes in long-term elasticities over time.

c. Fuel Pricing

Let us assume that the energy substitution sequence corresponding to the energy price shocks occurs over $t = 1, \dots, T$ distinct time periods. The driving variables shall then be t sets of price changes for the n fuels, p_{jt} , $j = 1, \dots, n$, $t = 1, \dots, T$, representing the percentage price change in fuel j for time t , resulting in a matrix of dimension $(n \times T)$:

Percentage Price changes

f_1	p_{11}	p_{12}	.....	p_{1T}
f_2	p_{21}	p_{22}	.....	p_{2T}
\downarrow	\downarrow	\downarrow		\downarrow
f_n	p_{n1}	p_{n2}	.....	p_{nT}

The price data is used in the equations in sections 7.1 and 7.2 to determine the output and energy demand adjustment factors.

d. Exogenous (constant energy price) Growth Rates

For each of these periods and each subsector, a set of exogenous growth rates r_{jt} must be specified under the assumptions of constant energy prices. They represent an $(m \times T)$ matrix:

Percentage Price changes

s_1	r_{11}	r_{12}	.....	r_{1T}
s_2	r_{21}	r_{22}	.....	r_{2T}
\downarrow	\downarrow	\downarrow		\downarrow
s_m	r_{m1}	r_{m2}	.....	r_{mT}

These values are used in equation (9) (see Section 7.3) to determine the growth/decline of each subsector's output before incorporating price effects.

e. Adjusting the Output Values

The output values determined from the above growth rates must be adjusted by using information on the fuel mix, price changes and previous output. This is accomplished using equations (7 and 8) (see Section 7.2). This yields a new value-added vector which gives the output of each subsector. Note that this calculation precedes the energy use calculation. The use of lagged variables makes it necessary to approximate the fuel fractions in the calculated period as being roughly equivalent to the previous period. In the case of most interest here, all fuel prices will be rising. Furthermore, cross-price elasticities are not incorporated into the model. These two factors make the approximation for fuel fractions quite reasonable.

f. Energy Use Calculations

Energy demand is calculated using energy use by fuel and subsector based on the previous period's value, the adjusted growth rate of the subsector, the price changes, and the elasticity. A matrix of energy values is produced of the same form as the initial base year matrix. Note that energy use data is calculated *after* IAC social product is adjusted for energy price increases. This allows for the expected current-period growth to be figured into the determination of energy consumption. Together with the adjusted output values, this energy use matrix can be used to calculate the energy intensity and fuel fraction. Thus, the calculation of the energy use matrix is sequential, with each period's results found from the energy use matrix of the previous period.

APPENDIX C
Incorporation of Time Lags in the Industrial Model

In the IAC Sector Energy Demand Model, the long-run responses to price changes are modeled as instantaneous adjustments in the amounts of energy used and in IAC output. In the real world, truly instantaneous adjustments are not realistic. Although prices may significantly change within a short period of time, responses usually take place gradually. The Industry Model must, therefore, be seen as a simplification of the real world which portrays the long-run effects without paying attention to the adjustment path of the economy and of the different industrial subsectors in particular.

It is possible to incorporate a gradual adjustment process into the model through lagged price effects. Doing so requires year-to-year calculations of the changes. What this means is that including lagged effects would make the model significantly larger and less suited for more long-run energy analysis using a microcomputer-based spreadsheet format. For these reasons we chose not to include the lagged effects in the final version of the RMA industrial sector energy demand model for Lithuania.

The calculation procedures of the model are reviewed to understand how it could be made more dynamic. For simplicity assume that there is only one industry, say mining, and consider only one energy input, say electricity (El). How does the use of this input respond to a changing price of electricity (P)? Recall that the response depends on the price elasticity of (ϵ) electricity:

$$\epsilon = \left(\frac{\frac{dEl}{El}}{\frac{dP}{P}} \right) \quad (1)$$

Rearranging this equation:

$$\left(\frac{dEl}{El} \right) = \epsilon \times \left(\frac{dP}{P} \right) \quad (2)$$

and integrating it with $\{P_t, P_{t-1}\}$ and $\{El_t, El_{t-1}\}$ as the limits of integration, we obtain the following "stock-adjustment" equation:

$$\ln(El_t) - \ln(El_{t-1}) = \epsilon \times [\ln(P_t) - \ln(P_{t-1})] \quad (3)$$

Taking the exponent of both sides leaves us with:

$$\left(\frac{El_t}{El_{t-1}} \right) = \left(\frac{P_t}{P_{t-1}} \right)^\epsilon \quad (4)$$

which is the formula used in the model. This formula implicitly assumes that the entire change occurs in the time interval specified, in this case between time t-1 and time t. As was mentioned above, if the interval between t-1 and t is a short period (e.g. one year), this is not a very realistic way of modeling the adjustment process of an industry. It is much more likely to assume that an industry adjusts partially in the first year to the current price

change and then keeps adjusting for the following years. This idea can easily be included into the formula above by assuming that the electricity demanded adjusts to the weighted average of the price changes during the last N years. Let λ be the weights then the above formula generalizes to:

$$\left(\frac{El_t}{El_{t-1}} \right) = \exp \left[\epsilon \times \sum_{i=1}^N \lambda_i \times \ln \left(\frac{P_{t-i+1}}{P_{t-i}} \right) \right] \quad (5)$$

Where:

$$\sum_{i=1}^N \lambda_i = 1 \quad (6)$$

To test whether and how this formula works. Let us look at the case where $P_t = P_{t-1} = \dots = P_{t-N}$, ie. no price change occurs. Then,

$$\left(\frac{El_t}{El_{t-1}} \right) = \exp \left[\epsilon \times \sum_{i=1}^N \lambda_i \times \ln(1) \right] = \exp(0) = 1 \quad (7)$$

So, if there are no price changes then the amount of electricity used in the mining industry remains unchanged over time which is what we should expect. Now let us look at the weights and assume that $\lambda_1 = 1$ and $\lambda_2 = \lambda_3 = \dots = 0$.

$$\left(\frac{El_t}{El_{t-1}} \right) = \exp \left[\epsilon \times \lambda_1 \times \ln \left(\frac{P_t}{P_{t-1}} \right) \right] = \left(\frac{P_t}{P_{t-1}} \right)^\epsilon \quad (8)$$

This is exactly the formula used in the model. Putting all the weight on the recent price change and none on price changes that occurred in previous years is the same as assuming that the change occurs instantaneously.

The values of the λ 's as well as the number of years over which the adjustment occurs are chosen by the user, and should be based on some prior knowledge about the behavior of the economy. For example, historical data could show that typically the industry in question takes about 3 years to fully adjust to a price change ($N=3$), but that the largest share of the adjustment takes place right away with decreasing shares as time progresses. If that is the case, then a possible way of modelling the adjustment would be to set $\lambda_1 = .6$, $\lambda_2 = .3$, and $\lambda_3 = .1$. The same kind of formula to model gradual adjustments can be used for all the energy inputs in each industry as well as in modeling the output responses of each industry.

USER'S GUIDE TO THE TRANSPORTATION SECTOR ENERGY DEMAND AND EMISSIONS MODEL

**LITHUANIA ENERGY PRICE REFORM PROJECT
USAID EMERGENCY ENERGY PROGRAM
FOR EASTERN AND CENTRAL EUROPE**

(USAID CONTRACT #: EUR-0015-C-00-1006-00)
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RESOURCE MANAGEMENT ASSOCIATES
of Madison, Inc.

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Appendices

Appendix A
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1.0 Introduction

The Transportation Sector Energy Demand and Emissions Model (Transportation Model) estimates energy demand and vehicle emissions for the freight and passenger transportation sectors (water, pipeline and air transportation are not included) for a base year and one future year.

Energy demand for the passenger and freight transport sectors is dependent in the model on future levels of economic activity, reflected in the indicators of social product (SP), industrial agricultural and construction sector social product (IACSP) and fuel prices. In order to utilize the model, data on economic indicators, fuel prices, elasticities, characteristics of the transportation fleet (e.g., fuel efficiency, load factor, etc.), base year passenger trip making and shipping rates, and forecasted fuel prices and economic growth rates must first be entered into the model.

The Emissions component references the results of the Energy Demand module to determine the emissions load for seven pollutants: CO₂, NO_x, SO₂, SPM (particulate), CO, HC (hydrocarbons) and Lead (from gasoline only). The emissions loads are dependant on the vehicle kilometers traveled, vehicle and power-plant emissions characteristics, vehicle fuel efficiencies, and roadway vehicle speeds. To investigate the emissions implications of a particular scenario, that scenario must first be modeled on the Energy Demand module.

The Transportation Model is based on the Quattro Pro® Version 4.0 (© Copyright 1987, 1992 by Borland International) spreadsheet software, which is a versatile spreadsheet software program implemented on IBM compatible microcomputers. Once the user becomes familiar with the Transportation Model and Quattro Pro®, the model can be expanded, updated and revised to better suit the user's needs.

Section 2.0 of this guide summarizes the model's structure and describes each of the model's six component files. *Figures 2a-7a* illustrate the contents and spacial arrangement of each file. An index of the macros used to move within each file, are presented in *Figures 2b-7b*. Section 3.0 discusses the "links" between the files and their proper use. The memory requirements of the various components of the model are outlined in section 4.0. The full model requires large amounts of microcomputer memory but options for using less memory are described. Much of the model is protected from being accidently changed by the user. Section 5.0 outlines how to "unprotect" cells so the user may update them. A detailed step-by-step guide to open files, enter data and run both the energy demand and emissions components of the model are outlined in section 6.0. The final section reviews the formulas used within the model.

2.0 Model Structure

2.1 General Model Structure

The Transportation Model is composed of over 100 separate worksheets in six linked Quattro Pro® spreadsheet files. The six Transportation Model files are linked in a hierarchical structure (*Figure 1*). The model has two segments; the Energy Demand and the Vehicle Emissions portions. The Energy Demand portion is composed of the TRAN-ECO, FREIGHT, PASSENG and TRAN-SUM files. The emissions portion of the model is composed of the EMISD and EMISC files. It uses data from the FREIGHT and PASSENG and TRAN-ECO spreadsheet files.

2.2 Modeling Years

The Transportation Model computes energy demand and emissions load for a base year and one future year. The base year been set at 1990 for the Lithuania version of the model. The model is currently designed to run the future years 1992, 1994, 1996, 1998 or 2000. Two summary tables, one in each of the EMISC and TRAN-SUM files, are constructed to present values for 1990, 1994 and 2000. **The values in these two tables will only be correct if first 1994 and then 2000 are modeled sequentially.**

2.3 Macros

In the upper left-hand corner of each of the six spreadsheets is a macro menu (presented in figures 2b - 7b). Macros are small internal programs which are activated by concurrently pressing the "alt" key and a designated letter key. In this model the macros are used to move between worksheets within each file, view graphs and print summary tables. The macro programs are written on the upper right corner of each spreadsheet.

2.4 Spreadsheet Files

The files which compose the Transportation Model are described below. *Figures 2-7* provide a spacial diagram of the worksheets within each file and each file's macro menu.

1. **TRAN-ECO:** This is the economic (ECO) driver of the transportation model. The TRAN-ECO file is linked to the PASSENG and FREIGHT spreadsheet files (*Figure 1*). Its primary function is to calculate four adjustment factors. These adjustment factors determine the effects of changes in fuel price and economic growth rates upon usage rates and energy efficiency of the transportation system. They are calculated from SP (Social Product), IACSP (Industrial Agricultural and Construction Sector Social Product), fuel price, vehicle life and the corresponding elasticity. They are used to "adjust" base-year transportation characteristics (passenger trip making rates, freight shipping rates, and vehicle fuel efficiencies) to model the transportation

characteristics of the future year, in the **FREIGHT** and **PASSENG** spreadsheet files. See section 7.0 for a detailed discussion and derivation of adjustment factors.

- 2 & 3. **PASSENG** and **FREIGHT**: These spreadsheets use the vehicle characteristic [fuel type, load factor (tons or passengers per vehicle) and fuel efficiency], trip making characteristics (average trip length, trips per day by vehicle type, and geographic zone), and the adjustment factors from **TRAN-ECO** to calculate energy demand for the base and future years.
4. **TRAN-SUM**: This file contains summary tables and graphs of passenger and freight energy demand and energy intensity. Data from the Transportation Model can be used with the Long-Range Energy Alternatives Planning Model (LEAP) (Tellus Institute, 1990). To simplify use of the Transportation Model with the LEAP model, a worksheet is modeled after the LEAP transportation energy demand input module.
5. **EMISD**: The **EMISD** (emissions data) file contains data on vehicle and power-plant emission factors (for CO₂, SO₂, NO_x, SPM (particulate), CO, HC (hydrocarbon) and lead (for gasoline only)), vehicle kilometers and fuel consumption by diesel trains. The emission coefficients can be calibrated to more accurately simulate the characteristic of the nation's vehicle stock and electric-power generation facilities. The vehicle emission factors currently used in the model are from American pre-emission control vehicles of the early 1970's.
6. **EMISC**: The **EMISC** (emissions calculation) spreadsheet file uses the emission factors from **EMISD** and the distance traveled by each transportation mode, fuel consumption and fuel efficiencies from the **PASSENG** and **FREIGHT** files to calculate the transportation sector's emissions for the base and a future year. The procedures for calculating emission loads are described in Section 7.6.

3.0 Linked Files

3.1 Linked Files and Linking Formulas

The six Transportation Model spreadsheet files are linked to one another to allow data to flow between files (*Figure 1*). Linked spreadsheet files allow larger models to be built by breaking the model down into several component files. Links allow any or only one set of a model's files to be on screen at once. The total number of spreadsheets that maybe opened at once depends on the available computer memory (see section 4.0). The spreadsheet files are linked when a cell in one file refers to a cell of another file. For example, a formula in the PASSENG file may refer to the value in cell "[TRAN-ECO]R34", or the value in cell R34 of the TRAN-ECO file.

3.2 Proper Use of Linked Files

Care should be taken when the user changes a value in spreadsheet file "A" that is linked to a formula, say in cell "D3", of spreadsheet "B". Only when spreadsheet B is **open** will all formulas in spreadsheet B which directly or indirectly refer to cell D3 be recalculated. If file B is **closed** the value of cell D3 will be updated but formulas which refer to cell D3 within file B or other linked files referring to D3, will **NOT** be recalculated. For example if the user has opened TRAN-ECO and TRAN-SUM only and updates a fuel price on TRAN-ECO, the user will not see any changes in energy demand from FREIGHT and PASSENG on the TRAN-SUM file. This is because the intermediate spreadsheets, FREIGHT and PASSENG, are not open and therefore the formulas referring to fuel price have not recalculated energy demand (shown in the TRAN-SUM file).

When retrieving any linked file, say file B, from memory, the computer will ask if the user wishes to: "load supporting", "update references", or "none". "Load Supporting" will load all files which are linked to file B. At times, available memory will not allow all supporting files to be loaded. To use less memory, use "Update References". Update references accesses all values which are linked to file B and updates those values without loading each supporting file. Choosing "None" temporarily replaces linked values from closed supporting files with a "NA" (not available) value.

3.3 The Background Recalculation (BKGD) Flag

As formulas are recalculated the BKGD (Background Recalculation) flag appears at the bottom of the computer screen. When RAM memory is nearly fully utilized, the recalculation of all formulas may take a few minutes. This long recalculation time is common when several linked spreadsheets are active. The results of the Transportation Model are incorrect while the BKGD flag is on screen.

Figure 1. Structure of RMA Transportation Energy Demand and Emissions Model

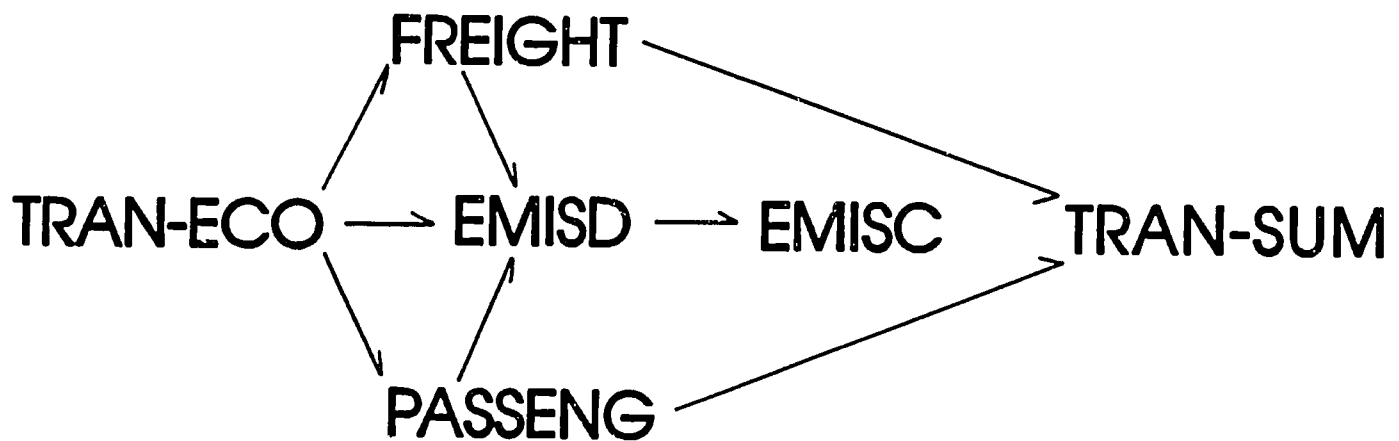


Figure 1: The structure of the RMA Transportation Energy Demand and Emissions Model. Arrows indicate the links and directions of information flow.

Figure 2a. Spatial Location of Worksheets in TRAN-ECO Spreadsheet

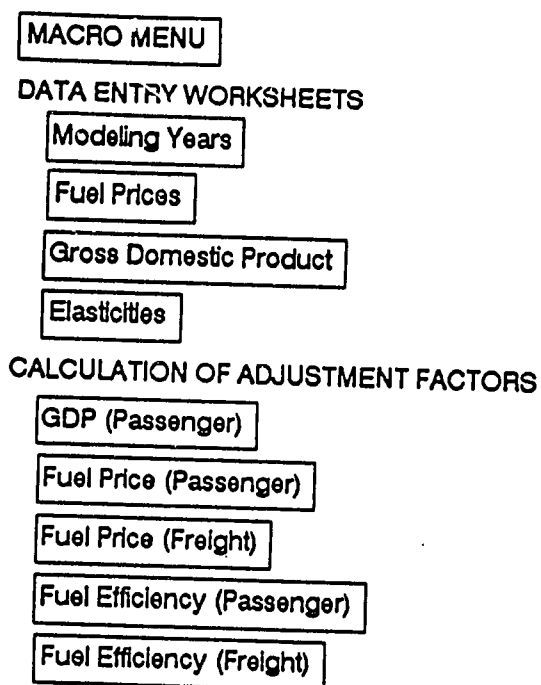


Figure 2b. TRAN-ECO Spreadsheet File Macro M

Economic Driver (data input)	
ALT A	Modeling years
ALT B	Fuel prices
ALT C	Gross Domestic Product
ALT D	Gross Domestic Product of Industry
ALT E	Elasticities
Calculation of Adjustment Factors (calculated by model)	
ALT F	GDP - passenger
ALT G	Fuel price - passenger
ALT H	Fuel price - freight
ALT I	GDP of Industry - freight
ALT J	Fuel efficiency - passenger
ALT K	Fuel efficiency - freight

Figure 3a. Spatial Location of Worksheets in PASSENG Spreadsheet File

Macro Menu	Passenger Trips / Day Base Year	Vehicle Km Base Year	Passenger KM / Year Base Year	Fuel Use by Fuel Type Base Year	Fuel Use in Giga Joules Base Year
Vehicle Characteristics					
Adjustment Factors for Trip Making	Passenger Trips / Day Scenario Year	Vehicle Km Scenario Year	Passenger Km / Year Scenario Year	Fuel Use by Fuel Type Scenario Year	Fuel Use in Giga Joules Scenario Years

Figure 3b. PASSENG Spreadsheet Macro Menu

Data Input

ALT-A Vehicle characteristics

ALT-B Trip making rates base year

Passenger trips per day by mode and fuel type

ALT-B Base Year

ALT-C Scenario Year

Vehicle KM by mode and fuel type

ALT-D Base Year

ALT-F Scenario Year

Passenger KM by mode and fuel type

ALT-G Base Year

ALT-H Scenario Year

Fuel Use (KWH and liters) by mode

ALT-J Base Year

ALT-K Scenario Year

Fuel Use (gigajoules) by mode

ALT-L Base Year

ALT-M Scenario Year

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Figure 4a. Spatial Location of Worksheets in FREIGHT Spreadsheet File

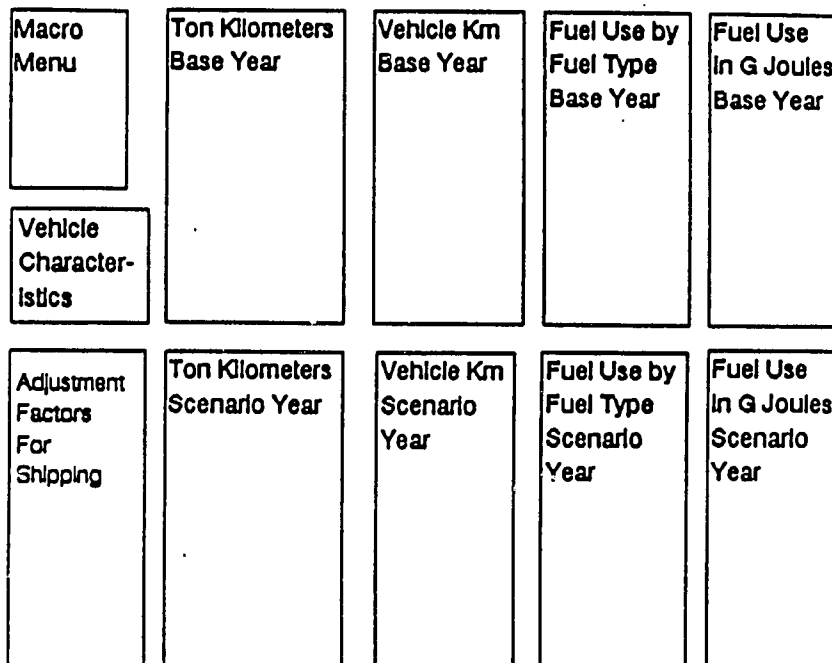


Figure 4b. FREIGHT Spreadsheet File Macro Menu

Data Input

ALT-B Base Year ton-km
ALT-A Vehicle Characteristics

Ton KM by mode and fuel type

ALT-B Base Year
ALT-C Scenario Year

Vehicle KM by mode and fuel type

ALT-D Base Year
ALT-F Scenario Year

Fuel use (litres, kwh) by mode and fuel type

ALT-G Base Year
ALT-H Scenario Year

Fuel use (gigajoules) by mode and fuel type

ALT-J Base Year
ALT-K Scenario Year

Figure 5a. Spatial Location of Worksheets in TRAN-SUM Spreadsheet File



Figure 5b. TRAN-SUM Spreadsheet File Macro Menu

- ALT-A -Freight energy use
- ALT-E -Passenger energy use

- Graphs for passenger transportation energy use
 - ALT-Q -Energy use by fuel type
 - ALT-R -Energy intensity by fuel type
 - ALT-S -Energy use by mode
 - ALT-T -Energy intensity by mode

- Graph for net energy use by transportation sector
 - ALT-V -Energy by fuel type

- Printing summary tables
 - ALT-B -Freight energy use
 - ALT-C -Passenger energy use
 - ALT-D -Net energy use
 - ALT-H -Net energy use in LEAP format

Figure 6a. Spatial Arrangement of Worksheets Within the EMISD Spreadsheet

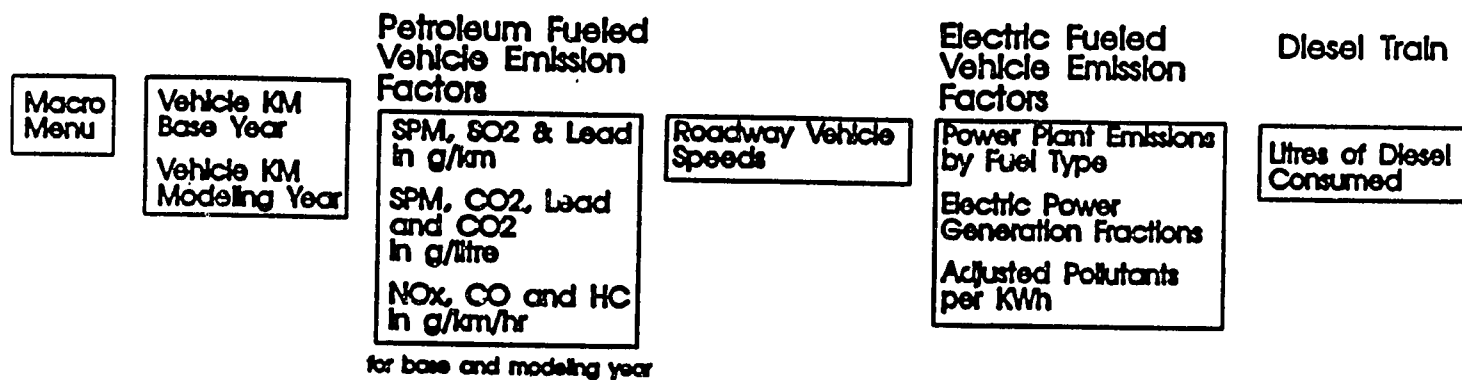


Figure 6b. EMISD Spreadsheet File Macro Menu

MARCO MENU	
Vehicle Km	
"ALT-A" NA	
"ALT-B" NA	
DATA INPUT	
Petroleum Fueled Vehicles	
Emission Factors (grams/km)	
"ALT-C" SPM, SO2 and Lead - base year	
"ALT-D" SPM, SO2 and Lead - modeling year	
Emission Factors (grams/litre fuel)	
"ALT-E" SPM, SO2, Lead and CO2 - base year	
"ALT-F" SPM, SO2, Lead and CO2 - modeling year	
Emissions Factors (grams/km/hr)	
"ALT-G" NOx - base year	
"ALT-H" NOx - modeling year	
"ALT-I" CO - base year	
"ALT-J" CO - modeling year	
"ALT-K" HC - base year	
"ALT-L" HC - modeling year	
"ALT-M" roadway vehicle speeds	
Electric Powered Vehicles	
"ALT-N" power plant emissions	
"ALT-O" generation fraction	
"ALT-P" pollutants from power generation	
Diesel Fueled Trains	
"ALT-Q" diesel consumption	

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Figure 7a. Spatial Arrangement of Worksheets Within the EMISC Spreadsheet File

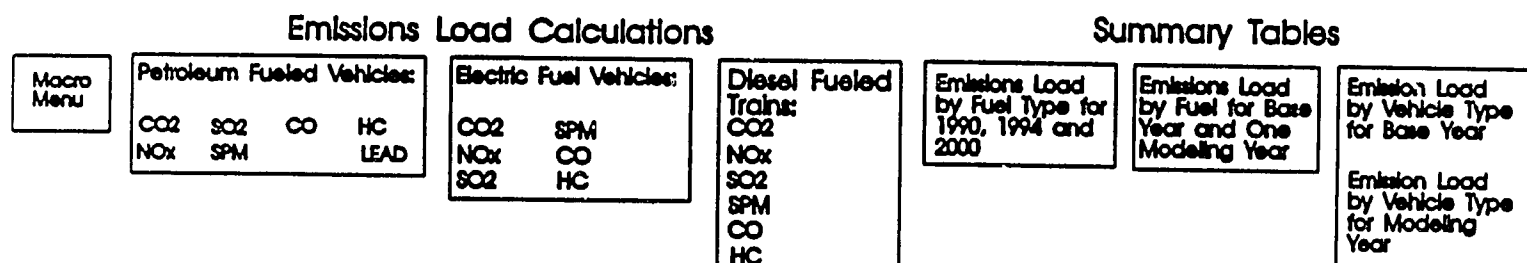


Figure 7b. EMISC Spreadsheet File Macro Menu

Macro Menu

CALCULATION TABLES

Petroleum Fueled Roadway Vehicles

- *ALT-A* CO2 emissions
- *ALT-B* NOx emissions
- *ALT-C* SO2 emissions
- *ALT-D* SPM emissions
- *ALT-E* CO emissions
- *ALT-F* HC emissions
- *ALT-G* Lead emissions

Electric Powered Vehicles

- *ALT-H* CO2 emissions
- *ALT-I* NOx emissions
- *ALT-J* SO2 emissions
- *ALT-K* SPM emissions
- *ALT-L* CO emissions
- *ALT-M* HC emissions

Diesel Fueled Trains

- *ALT-N* CO2 emissions
- *ALT-O* NOx emissions
- *ALT-P* SO2 emissions
- *ALT-Q* SPM emissions
- *ALT-R* CO emissions
- *ALT-S* HC emissions

SUMMARY TABLES & GRAPHS

Emission Loads by Fuel Type

- *ALT-T* for Base and Modeling Year
- *ALT-U* for 1990, 1994 and 2000

Emission Loads by Vehicle Type

- *ALT-V* for Base Year
- *ALT-W* for Modeling Year

Graphs

- *ALT-X* Graph of Emissions Load

To Print Summary Tables

- *ALT-Y* Emissions Load (base and modeling year)
- *ALT-Z* Emissions Load by Vehicle Type (base and modeling year)

4.0 Memory Requirements

To run the Transportation Sector Energy Demand and Emissions Model, the user's IBM compatible computer must have at least 375,000 bytes of random access memory (RAM) available when Quattro Pro® is loaded. If the user has Microsoft Windows®, additional memory can sometimes be freed-up if Quattro-Pro® is used outside the Window's® environment. To access Quattro Pro® from outside the Windows® environment simply type Q at the DOS prompt (ie C>). When RAM is nearing full utilization the user may be unable to view graphs and print tables or graphs. To view graphs or print, Save and Close the linked files.

The four linked files of the Energy Demand portion of the model require 500,000 bytes of RAM. If RAM is insufficient, either the FREIGHT side (TRAN-ECO, FREIGHT and TRAN-SUM) or the passenger side (TRAN-ECO, PASSENG and TRAN-SUM) can be opened and run separately. The freight and the passenger side use 225,000 and 350,000 bytes of RAM respectively.

The Emissions portion of the Transportation Model is composed of the EMISD and EMISC files, they are linked to the PASSENG and FREIGHT files, which are linked to the TRAN-ECO spreadsheet. To open the EMISC, EMISD, PASSENG, FREIGHT and TRAN-ECO files 650,000 bytes of RAM are required. Memory size limitations may dictate that the user set the data inputs as desired in the TRAN-ECO, FREIGHT and PASSENG spreadsheets, close all of them and then open the EMISD and EMISC spreadsheets. Memory will be sufficient if 325,000 RAM are available. The opening and closing of files is necessary for each spreadsheet file's constituent formulas to be recalculated using the updated input data.

5.0 Protection of Cells

The majority of cells in each spreadsheet are protected. A protected cell cannot be changed by the user. This safe-guards formulas, values and text from being altered by an inexperienced user. High lighted cells are not protected. The values in the unprotected cells can be changed by the user. These cells contain data that typically would be set or updated by the user; such as economic variables, vehicle types, vehicle characteristics and so forth.

To disable the protection for an entire spreadsheet, thereby allowing the user to change any cell, bring the desired spreadsheet on screen then type in the following sequence: /OPD . The "/" activates the menu options at the top of the screen, "O" stands for Options, "P" stands for Protection and "D" stands for Disable. To turn the protection back on, type /OPE ; where "E" stands for enable. An individual cell or group of cells can be unprotected by typing: /SPU ("S" stands for Style, "P" for Protection and "U" for Unprotect). Then using the arrow keys, block out the area you wish to unprotect then strike the "Enter" key.

6.0 Operating the Transportation Model

The following several pages outline the operation of the transportation model. The user must first open the model within Quattro Pro®. The user should first open TRAN-ECO and set the desired future years and economic data (fuel prices, elasticities etc.). The user should then move onto enter baseline data in the PASSENG and FREIGHT files. After all data is entered, the scenario can be "run" to calculate the energy use for the base and future years. Energy demand data is presented in the TRAN-SUM spreadsheet. The emissions spreadsheet files (EMISD and EMISC) can then be accessed (if necessary the emission coefficients can be updated) and the emissions load for the energy demand scenario can then be viewed.

It is suggested that inexperienced users follow the steps in the order presented below to familiarize themselves with the operation of the model.

6.1 Running the Energy Demand Portion

<u>Keystrokes</u>	<u>Action/Discussion</u>
1.	Open Quattro Pro®.
2. /F	Activates File Menu Options.
3. R	To Retrieve a file. The Transportation Model should already be installed on the hard drive of your computer. Move cursor, using the arrow keys, until TRAN-SUM is highlighted, then strike "Enter". The computer will then ask which "link option" you prefer. Choose "Load Supporting" and strike "Enter" this opens all spreadsheets (TRAN-ECO, FREIGHT and PASSENG) which are linked to the TRAN-SUM spreadsheet. If the message "there is not enough memory for this operation" appears then escape with the "esc" key. At this point it is advisable to open only one side of the energy demand model (the passenger or freight side). To do this, press /F followed by O (for "Open") and choose TRAN-SUM. Choose "Update Refs" at the Link Options message. Then repeat the process for the PASSENG or FREIGHT files.
4. /W	Activates the Window menu options.
5. S	Stacks all active spreadsheets. You should see three or four active spreadsheets.
6. Alt-O	Concurrently depress the "Alt" key and the "O" key. These key strokes allow you to move between spreadsheets. Move cursor to highlight TRAN-ECO and strike the "enter" key. The TRAN-ECO spreadsheet is now active.
7. "Home"	Strike the "Home" key. This action moves the user to the upper left-hand corner of the spreadsheet. You are now viewing the macro menu. Always press the "Home" key to return to the upper left-hand corner of the spreadsheet and the macro menu.
8.	The user can now move around the spreadsheet and update the unprotected values listed in <i>Table 1</i> . The user can utilize the arrow keys, page up-and

down keys, the tab and macros (see *Figure 2*) to move around the spreadsheet file. For example by simultaneously typing "Alt" and "B" the cursor moves to the upper left-hand corner of the fuel price worksheet.

Table 1: Unprotected Values Within The TRAN-ECO Spreadsheet

<u>CELL</u>	<u>CONTENTS</u>
F24	Future name
E31	Modeling year
D38-40	Fuel types
G38..L40	Fuel prices for 1989 - 2000
E38..F40	Annual fuel price growth rates
D50-59	Geographic zones
E50..I59	Annual SP exogenous growth rates
E69..J78	Annual IACSP exogenous growth rates (these can be taken from the RMA Industrial Energy Demand Model (Resource Management Associates 1991) for the same years).
ELASTICITIES	
E86	Income/SP elasticity of trip making
E90	Income/IACSP elasticity of shipping
E94-96	Fuel price elasticity of trip making by passenger vehicles
E100-102	Fuel price elasticity of shipping by freight vehicles
E107-109	Fuel price elasticity of passenger vehicles fuel efficiency
E114-116	Fuel price elasticity of freight transportation fuel efficiency
I106-108	Average vehicle life (years) of passenger vehicles
I113-115	Average vehicle life (years) of freight vehicles

<u>Keystrokes</u>	<u>Action/Discussion</u>
9.	After changes are completed in the TRAN-ECO file the user should move to the FREIGHT spreadsheet file.
10. <i>Alt-0</i>	Then move cursor to highlight "FREIGHT" and strike the "Enter" key. Now the FREIGHT spreadsheet is active.
11. <i>"Home"</i>	Strike the "Home" key. This action moves the user to the macro menu in the upper left-hand corner of the spreadsheet.
12.	The user can now move around the spreadsheet using macros (<i>Figure 4</i>) and update the unprotected values, listed in <i>Table 2</i> .

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Table 2: Unprotected Values Within The FREIGHT Spreadsheet

<u>CELL</u>	<u>CONTENTS</u>
-------------	-----------------

C39..H39	Vehicle types
----------	---------------

TRIP LENGTHS

C41..H41	for base year
----------	---------------

C42..H42	for future year
----------	-----------------

LOAD FACTOR

C44..H44	for base year
----------	---------------

C45..H45	for future year
----------	-----------------

FUEL EFFICIENCIES FOR BASE YEAR

C48..H48	for gasoline
----------	--------------

C49..H49	for diesel
----------	------------

C50..H50	for electricity
----------	-----------------

D78-134	IACSP adjustment factor override
---------	----------------------------------

F78-134	Fuel price adjustment factor override
---------	---------------------------------------

K10..P60	Ton kilometers/year by mode and fuel type for the base year
----------	---

<u>Keystrokes</u>	<u>Action/Discussion</u>
-------------------	--------------------------

13.	When updates are completed in the FREIGHT spreadsheet file, the user should move to the PASSENG spreadsheet.
-----	--

14. <i>Alt-0</i>	Then move cursor to highlight PASSENG and strike the "Enter" key. Now the PASSENG spreadsheet is active.
------------------	--

15. <i>"Home"</i>	This action moves the user to the macro menu in the upper left-hand corner of the spreadsheet.
-------------------	--

16.	The user can now move around the spreadsheet using the macros in <i>Figure 3b</i> and update the unprotected values listed in <i>Table 3</i> .
-----	--

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Table 3: Unprotected Values Within The PASSENG Spreadsheet.

<u>CELL</u>	<u>CONTENTS</u>
D37..M37	Vehicle types

TRIP LENGTHS

D39..M39	for base year
D40..M40	for future year

LOAD FACTORS

D42..M42	for base year
D43..M43	for future year

FUEL EFFICIENCIES FOR BASE YEAR

D46..M46	for gasoline
D47..M47	for diesel
D48..M48	for electricity
F82-138	SP adjustment factor override
H82-138	Fuel price adjustment factor override
P11..Y61	Passenger trips per day by mode and fuel type for the base year

<u>Keystrokes</u>	<u>Action/Discussion</u>
-------------------	--------------------------

- | | |
|-------------------|---|
| 17. | When the updates are completed you should move into the TRAN-SUM spreadsheet. |
| 18. <i>ALT-0</i> | Move cursor to highlight "TRAN-SUM" and strike the "Enter" key. |
| 19. <i>"Home"</i> | Once the spreadsheet has been retrieved, strike the "Home" key, to move to the macro menu. |
| 20. | There are no values to update on this spreadsheet. This spreadsheet summarizes the results of the FREIGHT and PASSENG spreadsheets on several different tables. Macros in the TRAN-SUM spreadsheet (<i>Figure 5</i>) open energy-demand and energy-intensity graphs (press the "ESC" key when completed viewing graphs) as well as printing summary tables for energy demand. |

If not enough memory exists to view graphs or print tables or graphs, **Save** and **Close** each of the files linked to TRAN-SUM (ie TRAN-ECO, PASSENG and FREIGHT). After viewing and printing graphs and tables the linked files can be opened easily using the */TUO* command (Tools, Update links, Open) then choose the spreadsheets you wish to open.

Note: The Total Energy Demand table is constructed to summarize data for 1990, 1994 and 2000. The values on this table will only be accurate if the user models 1994 and then models year 2000. The "CIRC" flag appears at the

bottom of the computer screen because formulas for the 1994 values in the Total Energy Demand table refer to the same cell where the formula is written. This flag should be ignored by the model user.

After the model user has calculated energy demand of a particular scenario, the emissions implications can now be calculated and viewed. First, the user must exit the Energy Demand portion of the model.

- 21. /F Activates File menu options.
- 22. V This "saVes all" of the active files. Only save those files whose updates you are satisfied with, by choosing "Replace" when the computer prompts you with "File Already Exists". If the user does **NOT** wish to save a file because it is in an unacceptable condition, select "Cancel" when prompted by the computer; "File Already Exists".
- 23. /F Activates File Menu Options.
- 24. X eXits the user from all active files and Quattro Pro®.

6.2 Running the Emissions Portion

After a Energy Demand Scenario has been modeled the resulting Emission Loads can be determined using the EMISD and EMISC spreadsheet files. The Emissions model has links to the PASSENG, FREIGHT and TRAN-ECO spreadsheet files.

Keystrokes Action/Discussion

- 1. Open the Quattro Pro® Program.
- 2. /F Activates File Menu Options.
- 3. R Move cursor, using the arrow keys, until "EMISD" is highlighted, then strike "Enter". Choose "Update References" on the "Link Options" menu and strike "Enter". This refreshes all the spreadsheet links to TRAN-ECO, FREIGHT and the PASSENG spreadsheet files and recalculates all linked formulas.
- 4. /TUO This key-stroke sequence allows the user to open an inactive linked file (eg EMISC, PASSENG, FREIGHT or TRAN-ECO). /T opens the Tools menu, U activates the Update links command and O triggers the Open (linked file) option. Under the Open option a list of all linked files, which are not currently active, are presented. Choose the EMISC file using the arrow keys then strike "Enter". Now both of the emission spreadsheet files are open.
- 5. /WS To stack the active files type /W (Window menu) and S (stack).
- 6. /WP This key-stroke sequence allows the user to move between active spreadsheets. Select the EMISD spreadsheet with the arrow keys and strike "Enter".
- 7. "Home" This action moves the user to the upper left-hand corner of the spreadsheet and macro menu.
- 8. The user can now move around the spreadsheet and update the unprotected values listed in Table 4.

Table 4: Unprotected Values Within The EMISD Spreadsheet

CELL CONTENTS
GASOLINE AND DIESEL EMISSION FACTORS (in grams/km traveled) BY VEHICLE TYPE

U15-26	NOx, base year
V15-26	SO2, base year
W15-18	Lead, base year (for gasoline vehicles only)
AD15-26	NOx, future year
AE15-26	SO2, future year
AF15-18	Lead, base year (for gasoline vehicles only)

GASOLINE AND DIESEL EMISSIONS FACTORS (in grams/litre of fuel consumed) BY VEHICLE TYPE

W35-48	CO2, base year
AH35-48	CO2, future year

FOR DIESEL FUELED TRAINS

U35-36	SPM, base year
V35-36	SO2, base year
Z69-70	NOx, base year
Z94-95	CO, base year
Z121-122	HC, base year
AD35-6	SPM, future year
AE35-36	SO2, future year
AI69-70	NOx, future year
AI94-95	CO, future year
AI121-122	HC, future year

GASOLINE AND DIESEL EMISSION FACTORS BY VEHICLE SPEED AND TYPE

U62..Y75	NOx, base year
U87..Y100	CO, base year
U114..Y127	HC, base year
AD62..AH75	NOx, future year
AD87..AH100	CO, future year
AD114..AH127	HC, future year

ROADWAY VEHICLE AVERAGE SPEEDS

AK11..AS11	Base year
AK12..AS12	Future year

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ELECTRIC POWER EMISSIONS AND POWER GENERATION MIX

AW12-BB17 power plant emissions (by fuel type and pollutant)

AW25..BB25 base year, electric power generation mix

AW26..BB26 future year, electric power generation mix

9. */WP* After updates are made the user may now view the pollutant load implications of the energy demand scenario. To do this the user must move to the EMISC spreadsheet file. The */WP* key-stroke sequence allows the user to move between active spreadsheets. Select the EMISC spreadsheet with the arrow keys and strike "Enter".
10. *"Home"* The user is now at the upper left hand corner, the macro menu. The Macro Menu is presented in *Figure 7b*
11. The user may view and print the emissions load of the scenario by using the macro commands (*Figure 6b*). Macros in the EMISC spreadsheet display net emissions load tables, graphs (press the "ESC" key when completed viewing graphs) and print summary tables (the marco for the print command will have to be rewritten if the printer is unable to "Print to Fit").

If memory limitations do not allow the user to view and print graphs or tables, **Save** and **Close** the files linked to EMISC.

Note: One of the emission load tables is constructed to summarize data for the years 1990, 1994 and 2000. The values on this table are only guaranteed to be accurate if the user sequentially models 1994 and then 2000. The "CIRC" flag will be present at the base of the computer screen, because formulas for the 1994 values in the total emissions Load table refer to the same cell in which the formula is written. The flag should be ignored by the model user.

If the model user wishes to view the emissions implications of a different scenario (or future year), and enough memory exists to have EMISD, EMISC, TRAN-ECO, FREIGHT and PASSENG open, the user may simply make the necessary changes and then wait until recalculations are complete (the BKGD flag will turn off). If memory space is lacking, close the emissions spreadsheets (following steps 13 & 14 below) open TRAN-ECO, FREIGHT and PASSENG, make the desired changes, then close those files (following steps 21-24 above) and then open the EMISD and EMISC files (following steps 1-4 above).

To exit the emissions portion of the model:

13. */F* Activates File Menu Options.

14. *X* This will Exit the user from each active spreadsheet. If the user is satisfied with the condition of each file and wants to save the new file with the results, instruct the computer to "SAVE & EXIT" when asked "Lose your changes and Exit?" and "REPLACE" when informed that "File already exists".
If a file is in a unacceptable condition and the user does not wish to save the changes select "Yes" when asked; "Lose your changes and Exit?".

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7.0 Calculation Procedures

7.1 Calculating Future Values of Net Material Product and Net Industrial Product

It is assumed that citizen's trip-making rates are directly related to the health of the national economy, reflected by the Social Product. The model requires the user to input *exogenous* projections for the underlying annual growth rates for Social Product (SP). The projections must be specified under the assumption of constant real energy prices. The SP of the future year (SP_f) is determined in the TRAN-ECO spreadsheet at the end of period i , as follows:

$$SP_f = SP_c \times (1 + r_i)^t \quad (1)$$

SP_c is the Social Product of the economy at the beginning of period i , r_i is the exogenously determined annual growth rate for period i , and t is the length in years of period i . The change in the SP of the base and future years are linked passenger trip making (section 7.2).

The FREIGHT energy demand is assumed to be affected by the growth (or decay) of the industrial, agricultural and construction sectors. Projections of Industrial, Agricultural and Construction Sectors Social Product (IACSP) are linked to variations in shipping rates. Projections for the IACSP can be calculated by the RMA Industrial Sector Energy Demand Model (Resource Management Associates, 1992), using a formula analogous to formula (1). (Forecasts of exogenous IACSP from other sources can be used). In the RMA Industrial Model the forecasted variations in industrial, agricultural and construction sector output are adjusted by the effects of changing fuel prices (see Section 7.1, Industrial Model, Resource Management Associates, 1992). The price-adjusted growth rates were then entered into the TRAN-ECO spreadsheet file in the Transportation Model.

7.2 Determining Adjustment Factors for Future Year Shipping and Trip Making Rates

7.2.1 SP and IACSP Adjustment Factors

In the passenger transportation portion of the model, the number of passenger trips in the future year is dependent upon the impact of (elasticity between) variations in fuel prices and SP on trip making. The relationship between SP, fuel price and future year trip making rates are quantified by two elasticity terms, the fuel price and SP elasticities of trip making. The SP elasticity is defined as:

$$E_{sp} = (\partial T/T)/(\partial SP/SP)$$
$$E_{sp} \times (\partial SP/SP) = (\partial T/T)$$

where:

E_{sp} = trip making elasticity of social product
 ∂T = derivative of trip making rate
 T = trip making rate
 ∂SP = derivative of social product
 SP = current social product

Integrating both sides with the base-year and future-year trips (T_c, T_f) and SP (SP_c, SP_f) as the limits of integration and solving for the future trips, we obtain:

$$T_f = 10\exp[E_{sp} \times (\log SP_f - \log SP_c) + \log T_c] \quad (2)$$

where: T_f = trips, future
 E_{sp} = trip making elasticity of SP
 SP_f = SP, future (future year)
 SP_c = SP, current (base year)
 T_c = trips, current
(exp = exponent)

Normalizing the current number of trips, T_c , to one in formula (2) and setting T_f equal to AF_{sp} , results in:

$$AF_{sp} = 10\exp[E_{sp} \times (\log SP_f - \log SP_c)] \quad (3)$$

where: AF_{sp} = the SP adjustment factor

The SP adjustment factor is used to adjust future year passenger trip-making rates based upon the health of the national economy (measured by SP). The trip making rate in the future year increases if the adjustment factor is greater than 1 or decreases if the adjustment factor smaller than 1. Formula (3) is used in the TRAN-ECO spreadsheet. An identical algorithms is used for determining the adjustment factors for freight shipping, except SP is replaced by the Industrial, Agricultural and Construction Sector Social Product (IACSP).

7.2.2 Fuel Price Adjustment Factors

A second type of adjustment factor is calculated within the TRAN-ECO file to determine the impact of changing fuel prices upon trip making and shipping rates.

$$AF_{fp} = 10\exp[E_{fp} \times (\log FP_f - \log FP_c)] \quad (4)$$

where: AF_{fp} = the fuel price adjustment factor
 E_{fp} = trip making/shipping elasticity of fuel price
 FP_f = fuel price future
 FP_c = fuel price current

7.3 Determining Future Year Trip Making and Shipping Rates

Future year passenger trip making rates are determined by multiplying base year trip making rates by both the SP and the fuel price adjustment factors, as in formula (5).

$$T_s = AF_{sp} \times AF_{fp} \times T_b \quad (5)$$

where: AF_{sp} = SP adjustment factor
 AF_{fp} = fuel price adjustment factor
 T_b = trips made in the base year
 T_s = trips made in the future year

Formula (5) is used within the PASSENG spreadsheet. A similar formula, which replaces AF_{sp} with AF_{iacsp} and T_b (where T_b is the tons shipped in the base year), is used within the FREIGHT spreadsheet, to calculate the future year shipping rate.

7.4 Determining Vehicle Fuel Efficiency Adjustment Factors

As fuel prices increase newly manufactured vehicles are modeled to be more fuel efficient. Future year fleet fuel efficiencies are dependent upon past changes in fuel prices, the fraction of vehicle stock that was replaced in each modeling interval and the elasticity factor which relates fuel price and fuel efficiency improvements of vehicles (the fuel price elasticity of fuel efficiency). First, the fraction of vehicles replaced during each modeling time interval (for example 1990 to 1992) is determined:

$$VF_{90-92} = VL/T_{90-92} \quad (6)$$

where: VF_{90-92} = vehicle fraction built between 1990 and 1992
 VL = average expected vehicle life
 T_{90-92} = number of years between 1990 and 1992

Then the incremental fuel efficiency adjustment factor is calculated for each modeling period (equation (7)).

$$AFife_{90-92} = 10\exp[E_{fe}(\log P_{92} - \log P_{90})] \quad (7)$$

where: $AFife_{90-92}$ = incremental fuel efficiency adjustment factor, 1990 to 1992
 E_{fe} = fuel price elasticity of fuel efficiency
 P_{92} = fuel price 1992
 P_{90} = fuel price 1990

The incremental fuel efficiency adjustment factor is then applied to the corresponding fraction of vehicles manufactured during that modeling period (equation (8)).

$$FER_{90-92} = AF_{fe_{90-92}} \times VF_{90-92} \quad (8)$$

where: FER_{90-92} = incremental fuel efficiency response, 1990 to 1992

The fuel efficiency response values are then added for each vehicle age group and added to the remaining fraction of vehicles built before the base modeling year (the pre-1990 fuel efficiency adjustment factor can be thought to equal 1). This equals the net fuel efficiency adjustment factor for that particular modeling interval (for example 1990 to 1994);

$$AF_{nfe_{90-94}} = P_{90vf_{94}} + FER_{90-92} + FER_{92-94} \quad (9)$$

where: $AF_{nfe_{90-94}}$ = net fuel efficiency adjustment factor for the 1994 future year
 $P_{90vf_{94}}$ = fraction of vehicles built before 1990 and still operating in 1994
 FER_{90-92} = fuel efficiency response 1990 to 1992
 FER_{92-94} = fuel efficiency response 1992 to 1994

The net fuel efficiency factors are calculated within the TRAN-ECO spreadsheet file and used in the PASSENG and FREIGHT spreadsheet files to adjust future year vehicle fuel efficiencies.

7.5 Calculating Energy Demand in the PASSENG and FREIGHT Spreadsheet Files

Energy demand within the PASSENG and FREIGHT spreadsheet files is calculated in a step-wise fashion. The daily passenger trip making rates by mode, zone and fuel type are:

- 1) multiplied by average trip length and 365 days/year (resulting in passenger kilometers/year)
- 2) divided by the load factor (resulting in vehicle km/year)
- 3) multiplied by vehicle fuel efficiency (resulting in liters/year or Kwh/year) and
- 4) converted to Tera-joules/year of fuel demanded.

In the FREIGHT spreadsheet file shipping rates (in Ton Km/year, by mode, zone and fuel type) are:

- 1) multiplied by load factor (resulting in vehicle kilometers/year);
- 2) multiplied by fuel efficiency (resulting in liters/year or Kwh/year consumed) and
- 3) converted to Tera-joules/year of fuel demanded.

7.6 Methodology used to Determine Vehicle Emissions

Emissions for electric powered and petroleum fueled vehicles are determined in four methods. Emissions for diesel and gasoline fueled roadway vehicles are calculated using emission coefficients for U.S. pre-emissions control levels.

Method 1, Roadway Vehicle emission coefficients for NO_x, CO, and HC (in grams of pollutant per vehicle-kilometer traveled), are dependent upon the speed of the vehicle. Therefore, average vehicle speed must be entered into the model. The calculated emissions values are then multiplied by the distance traveled, resulting in net emissions.

APPENDIX A
References

**Tellus Institute. 1991. LEAP: A Computerized Energy Planning System, Version 90.01.
January 1990. Revised May 1991.**

Resource Management Associates. 1992. Industrial Sector Energy Demand Model. August 1991.

Passenger Vehicle Trip Lengths:

- A47 Train
 $3615 \times 10^6 \text{ km} / 32.3 \times 10^6 \text{ p} = 112 \text{ km}$
- B47 Trolley Bus
 $1212.4 \times 10^6 \text{ km} / 303.1 \times 10^6 \text{ p} = 4 \text{ km}$
- C47 Bus, diesel
 $6677.2 \times 10^6 \text{ km} / 686.1 \times 10^6 \text{ p} = 9.73 \text{ km}$
- D,E47 Van and Car
estimated to equal trip length for taxi.
- F47 Taxi
 $221 \times 10^6 \text{ km} / 16.7 \times 10^6 \text{ p} = 13.23 \text{ km}$

Freight Vehicle Trip Lengths:

- A-D55 All Freight
 $26775 \times 10^6 \text{ km} / 170.01 \times 10^6 \text{ t} = 157.5 \text{ km}$
- 72% freight by train
27% freight by truck
if average trip length TRAIN = 185 km (estimated)
then; $.73 \times 185 + .27 \times \text{truck t} = 157.5$
and average trip length TRUCK = 83 km
- B-D55 Large Truck, Small Truck and Van
all treated as TRUCKS, with trip length = 83 km

Freight Load Factors:

- B54 Large Truck
 $38 \text{ t/v} [\text{maximum capacity}] \times .77 [\text{capacity of utilization}] = 29.26 \text{ t}$
- C54 Small Truck
 $19 \text{ t/v} [\text{maximum capacity}] \times .83 [\text{capacity of utilization}] = 15.77 \text{ t}$

Passenger Trips Per Day:

- A52 Train, diesel
for all trains; $32.2 \times 10^6 \text{ pt/year} \times \text{year} / 365 \text{ days} = 88219 \text{ pt/day}$
for diesel; $88219 \text{ pt/day} - 3600 \text{ pt/day} [\text{see below}] = 84619 \text{ pt/day}$
- A53 Train, electric
The only electrified rail is between Vilnius and Kaunas.
If we assume 20 one way trains/day then;
 $20 \text{ vt/day} \times 180 \text{ p/v} = 3600 \text{ pt/day}$
- B53 Trolley-Bus, electric
 $303 \times 10^6 \text{ pt/year} \times \text{year} / 365 \text{ days} = 830411 \text{ pt/day}$
- C52 Bus, diesel
 $686.1 \times 10^6 \text{ pt/year} / 365 \text{ days} = 1879726 \text{ pt/day}$
- E52 Car, gasoline
Assume all gasoline is used in cars and taxis.
Total gasoline demand for 1990 = $1.546 \times 10^6 \text{ t} \times 44 \text{ GJ/t} \times 0.0326 \text{ GJ} = 2086.6 \times 10^6 \text{ L/yr}$
Gasoline demand for cars; $2086.6 \times 10^6 \text{ L} - 8.2875 \times 10^6 \text{ L} [\text{used by taxis}] = 2078.3 \times 10^6 \text{ L}$
then, $2078.3 \times 10^6 \text{ L/yr} \times \text{vkm} / .075 \text{ L} \times 2 \text{ p/v} \times \text{trip} / 13.25 \text{ km} \times \text{yr} / 365 \text{ d} = 11.46 \times 10^6 \text{ ptrip/day}$
 $11.46 \text{ pt/day} / 3.7 \times 10^6 \text{ people} = 3 \text{ passenger trips/day per capita}$
- F52 Taxi, gasoline
 $16.7 \times 10^6 \text{ pt/year} / 365 \text{ days} = 45753 \text{ pt/day}$
fuel use; $221 \times 10^6 \text{ pkm/yr} \times 2 \text{ p} \times .075 \text{ L/vkm} = 8287500 \text{ L/yr}$

Tons Shipped per year:

A60 Train, diesel

$$\text{Net tkm/yr} = 19260 \times 10^6 \text{tkm}$$

$$\text{Net tkm/yr for diesel; } 19260 \times 10^6 \text{tkm} - 28 \times 10^6 \text{tkm [see below]} = 19232 \times 10^6 \text{tkm/yr}$$

A61 Train, electric

The only electrified rail is between Vilnius and Kaunas.

If we assume 40 one way freight trains/day then;

$$40 \text{vt/day} \times 621 \text{t/v} \times 365 \text{day/yr} = 28 \times 10^6 \text{tkm/yr}$$

B-D60 Truck, diesel

$$\text{Net} = 7336 \times 10^6 \text{tkm}$$

Estimated break down: 75% large trucks	= $5502 \times 10^6 \text{tkm}$
20% small trucks	= $1467 \times 10^6 \text{tkm}$
5% vans	= $366 \times 10^6 \text{tkm}$

KEY TO ABBREVIATIONS:

t-tonne

p-passenger

v-vehicle

pt-passenger trip

vt-vehicle trip

vk -vehicle kilometer

vmiles-vehicle mile

tk -tonne kilometer

pk -passenger kilometer

L-litre

us gal-United States gallon

cdngal-Canadian gallon

KJ-kilojoule

MJ-megajoule

GJ-gigajoule

KWH-kilowatthour

gce-grams coal equivalent

Kgce-kilogram coal equivalent

tce-tonnes coal equivalent

toe-tonne oil equivalent

DATA SOURCES for the BASE YEAR and BASE CASE SCENARIO DATA for the LITHUANIAN ENERGY DEMAND MODELS

CELL(S)	Reference
A,G,H-1	Table A-1, Lithuanian: National Accounts (Own Methodology), data compiled for USAID Emergency Energy Project 1/92.
A2..A11	Industrial, Agricultural and Construction Sector Outputs, Table A-1, Lithuanian: National Accounts (Own Methodology), and additional data, provided to USAID Emergency Energy Project 1991 by the government of Lithuania.
G2..G11	-"
A12	need
A13	need
A14	?
A15	?
A16..17	Table 40, Average tariff of electrical energy supplied to different consumer groups, from Lithuanian Energy 1990 Indices, pub.1991.
A18	Table 41, Average tariff of supplied heat, -"
C12..18	Estimated
H12..14	Table 2, untranslated table of oil product prices for 1991 and projected prices, for 1992, provided to USAID Emergency Energy Project by the government of Lithuania, 1/92
H15	Table 5, untranslated table of natural gas accounts and prices for 1991 and projected prices for 1992, -"
H16..17	Table 40, Average tariff of electrical energy supplied to different consumer groups, from Lithuanian Energy 1990 Indices, pub. 1991.
H18	Table 41, Average tariff of supplied heat, -"
I12..14	Document from the Lithuanian Energy Ministry, Energy Prices for 1-Jan-1992.
I15	Projected natural gas price as reported by Mike Ellis documentation of a meeting with the Lithuanian deputy minister of energy in his trip report, 11/91.
I16..18	Document from the Lithuanian Energy Ministry, Energy Prices for 1-Jan-1992.
A19..D27	Compiled from 4 tables of industrial consumption of heat, electricity, gas and oil, provided to USAID Energy Pricing Reform Project by the government of Lithuania, 1991.
A-F46	Estimated
A-C & F47	Compiled from tables of million passenger kilometers and passengers per year on public transportation, from Lithuanian Social Indices Year 1990, publ. Informacinis-Leidybinis Centras, Vilnius 1991, p148-149.
D,E47	Assumed to be identical to the average trip length of taxis.
A49,50	Czechoslovakian data provided by SEVEN for the USAID Emergency Energy Pricing Reform Project, 5/91.
B50,C49	"
D48,49	Fuel efficiency of a VW van as sold in the USA 1992 (according to VW officials a similar van is being sold in the Baltic Nations).
E,F48	Fuel efficiency of a used Yugo (compact car built in Yugoslavia) as sold in

Canada.

- A-C&F
51..53 Compiled from tables of million passenger kilometers and passengers per year on public transportation, from Lithuanian Social Indices Year 1990, publ. Informacinis-Leidybinis Centras, Vilnius 1991, p148-149.
- D51..53
A54 Same as the per capita automobile trip-making rate for Romania.
United Nations, 1990, Annual Bulletin of Transportation Statistics, United Nations, New York, 281P. (Data for Czechoslovakia.)
- B,C54 Livin, Alston L., 1984, Railways and Energy, World Bank Staff Working Papers, The International Bank of reconstruction and development, Washington DC, Number 634. 80p. (Data for France.)
- D54 Freight capacity of a VW van as sold in the USA 1992 (a similar van is being sold in the Baltic Nations).
- A,B54 Czechoslovakian data provided by SEVEN, for the USAID Emergency Energy Pricing Reform Project 5/91.
- C57 Livin, Alston L., 1984, Railways and Energy, World Bank Staff Working Papers, The International Bank of reconstruction and development, Washington DC, Number 634. 80p. (Data for France)
- D57,58 Fuel efficiency of a VW van as sold in the USA 1992 (a similar van is being sold in the Baltic Nations).
- A59..D61 Compiled from tables of million passenger kilometers and passengers per year on public transportation, from Lithuanian Social Indices Year 1990, publ. Informacinis-Leidybinis Centras, Vilnius 1991, p148-149. Truck shipping broken down into 3 vehicle types (see calculations section).

Notes:

CELL(S) Comment

- B22 Natural gas use in the construction and transportation sectors were combined in the data provided. It was assumed the 76% of the combined natural gas consumption was by the construction sector. This is the same ratio as for the consumption of heat for the two sectors.

SCENARIO DATA

-fuel prices

TRANSPORTATION ENERGY DEMAND MODEL, SCENARIO ASSUMPTIONS

SCENARIO ONE and ONE ALT

Pricing

Gasoline (rbls/litre)
Diesel (rbls/litre)
Elec. Transp. (r/kwh)

Annual Nominal Price Changes	Annual 90-92 C&P PI	Estimates of Annual Real Price Changes				
		1990-92	92-94	94-96	96-98	98-2000
90-92						
	100%	200%	20%	0%	0%	0%
	100%	200%	20%	0%	0%	0%
262%	100%	200%	20%	0%	0%	0%

SCENARIO TWO and THREE

Pricing

Gasoline (rbls/litre)
Diesel (rbls/litre)
Elec. Transp. (r/kwh)

Annual Nominal Price Changes	Annual 90-92 C&P PI	Estimates of Annual Real Price Changes				
		1990-92	92-94	94-96	96-98	98-2000
90-92						
	100%	50%	20%	0%	0%	0%
	100%	50%	20%	0%	0%	0%
262%	141%	50%	20%	0%	0%	0%

-gross social product

TRANSPORTATION SCEANARIOS

Gross Social Product

Scenarios ONE, ONE alt and TWO
Scenario THREE

Estimated Real Annual Growth Rate (% Change)					
91-92 estimated	93-94 estimated	95-96 estimated	97-98 estimated	99-2000 estimated	
-0.1	0	0.05	0.05	0.05	
-0.1	0.07	0.07	0.07	0.07	

-fuel efficiency elasticity of price

TRANSPORTATION SCENARIOS ONE, TWO and THREE

Fuel Efficiency Elasticity of Fuel Price

Gasoline
Diesel
Electricity

	Passenger	Freight
67	-0.4	-0.4
68	-0.4	-0.4
69	-0.4	-0.4

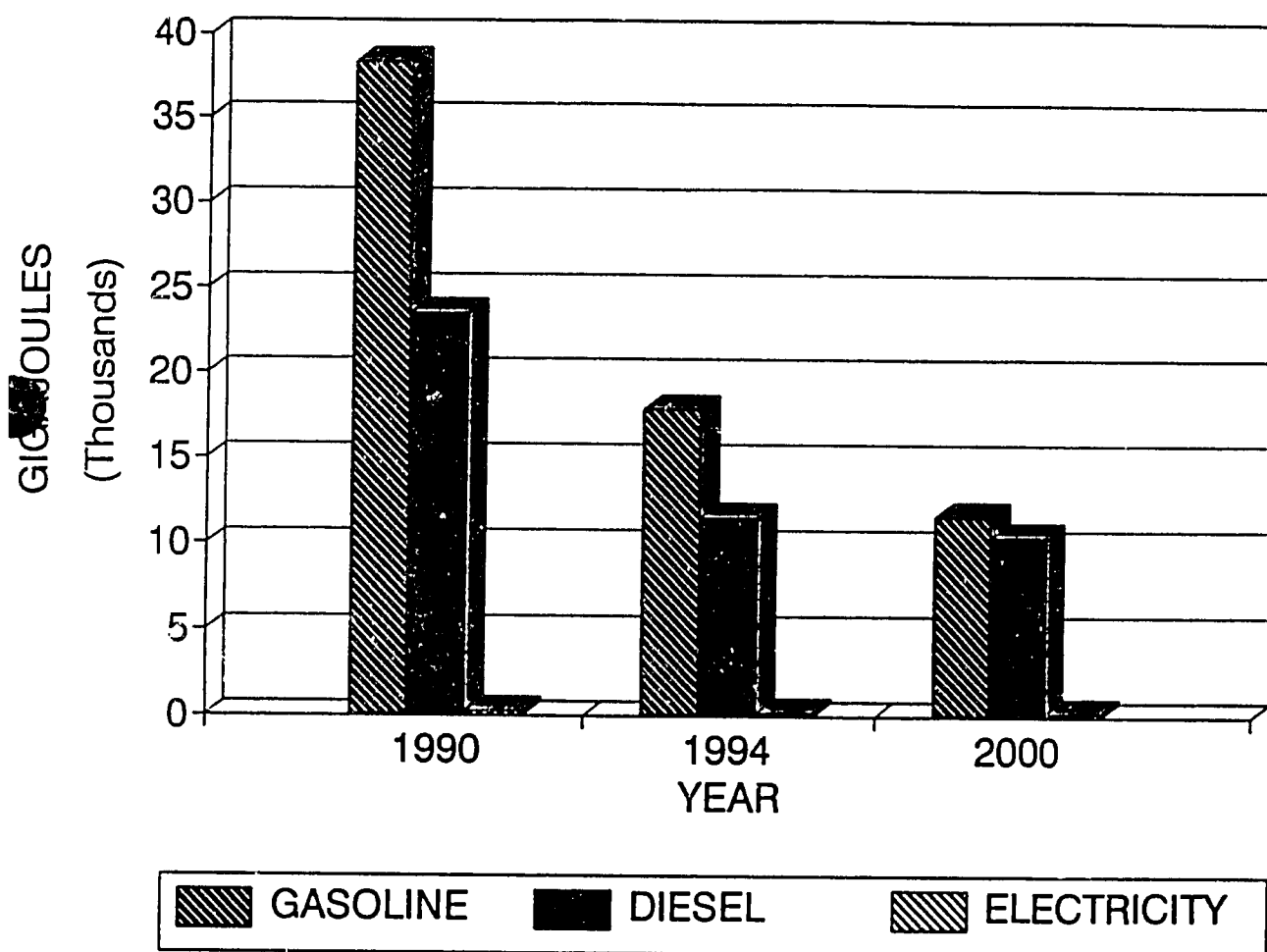
TRANSPORTATION SCENARIO ONE alt

Fuel Efficiency Elasticity of Fuel Price

Gasoline
Diesel
Electricity

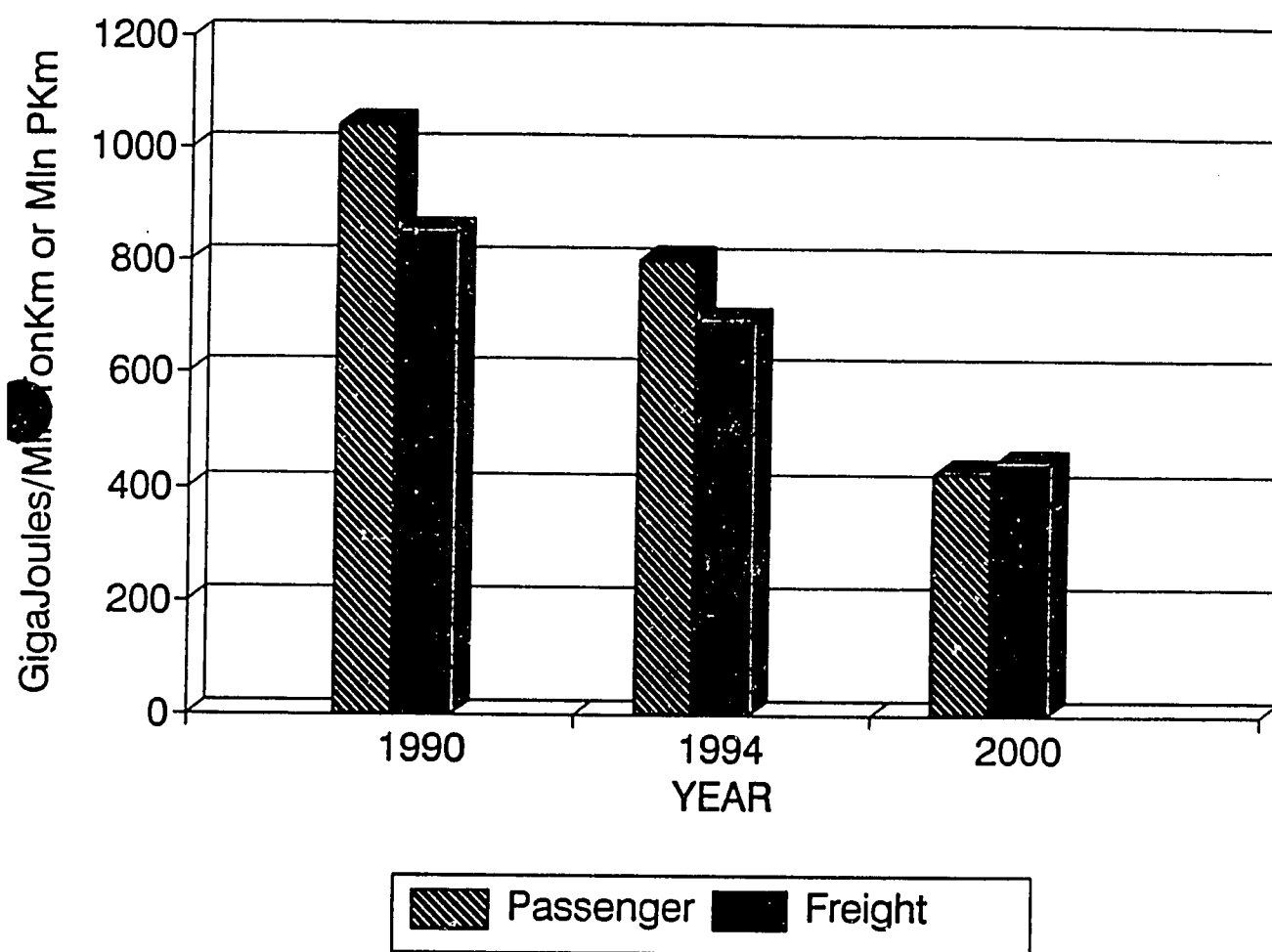
	Passenger	Freight
67	-0.2	-0.2
68	-0.2	-0.2
69	-0.2	-0.2

NET ENERGY USE BY FUEL TYPE



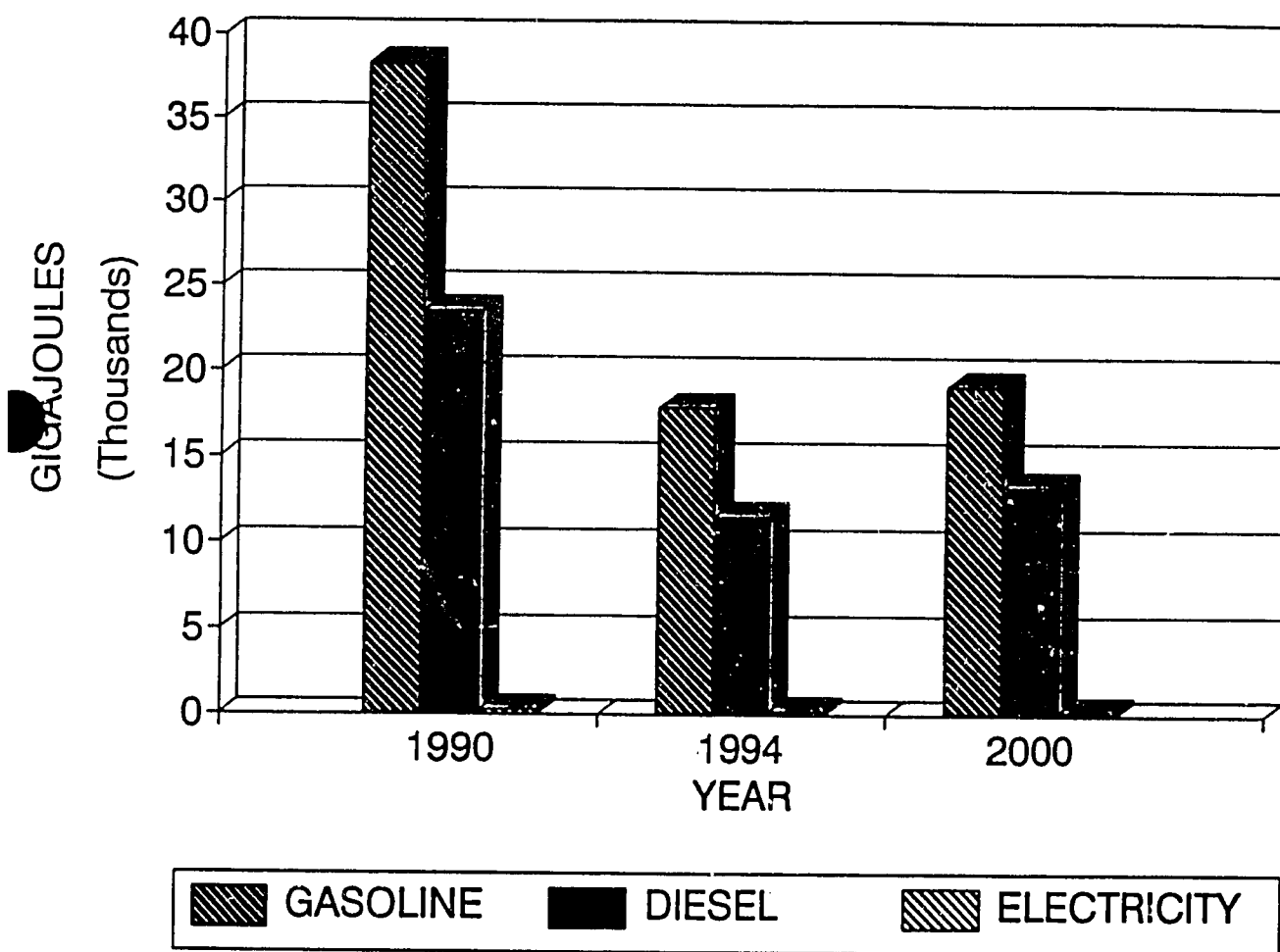
SCENARIO 1

TRANSP SECTOR ENERGY INTENSITY



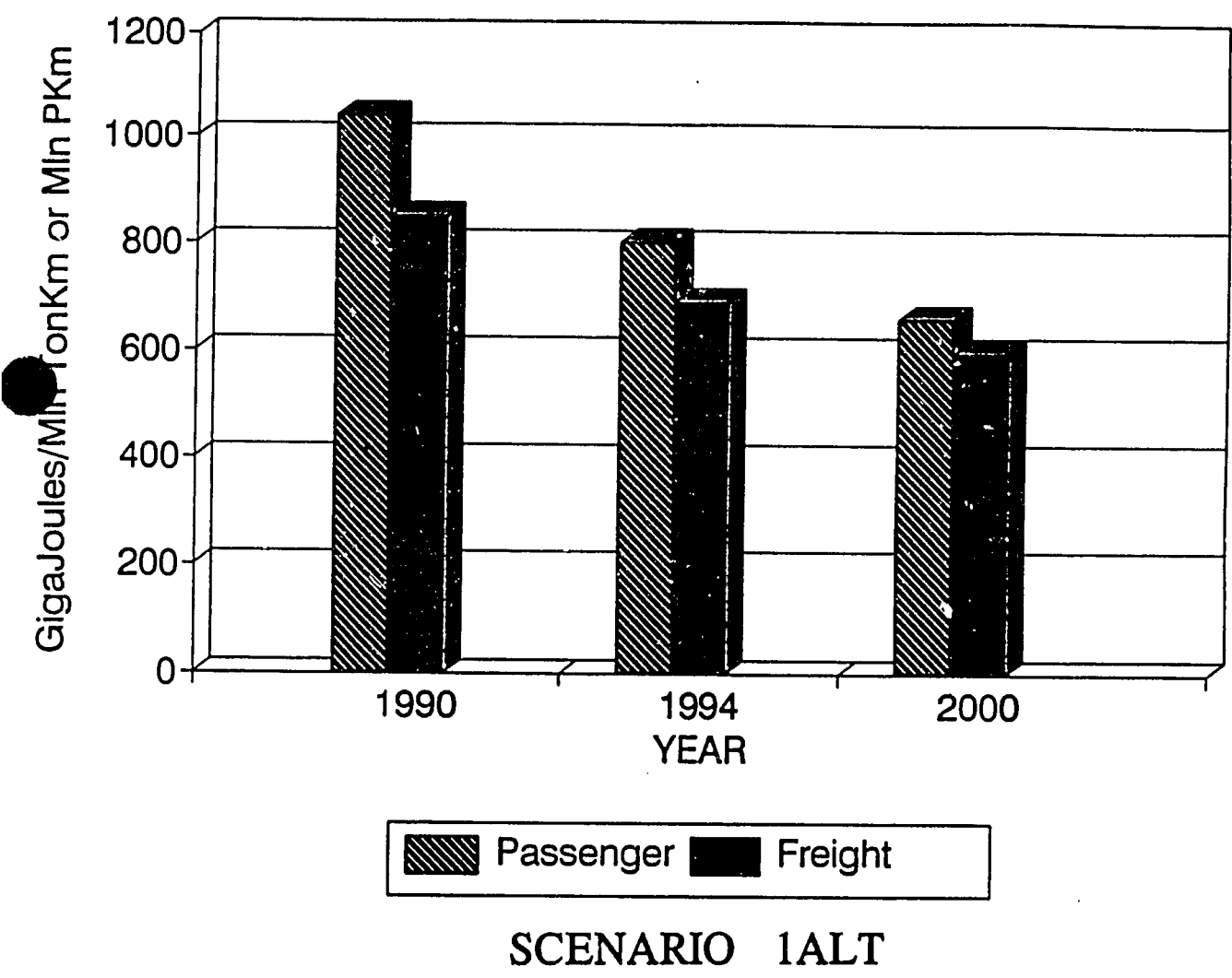
SCENARIO 1

NET ENERGY USE BY FUEL TYPE

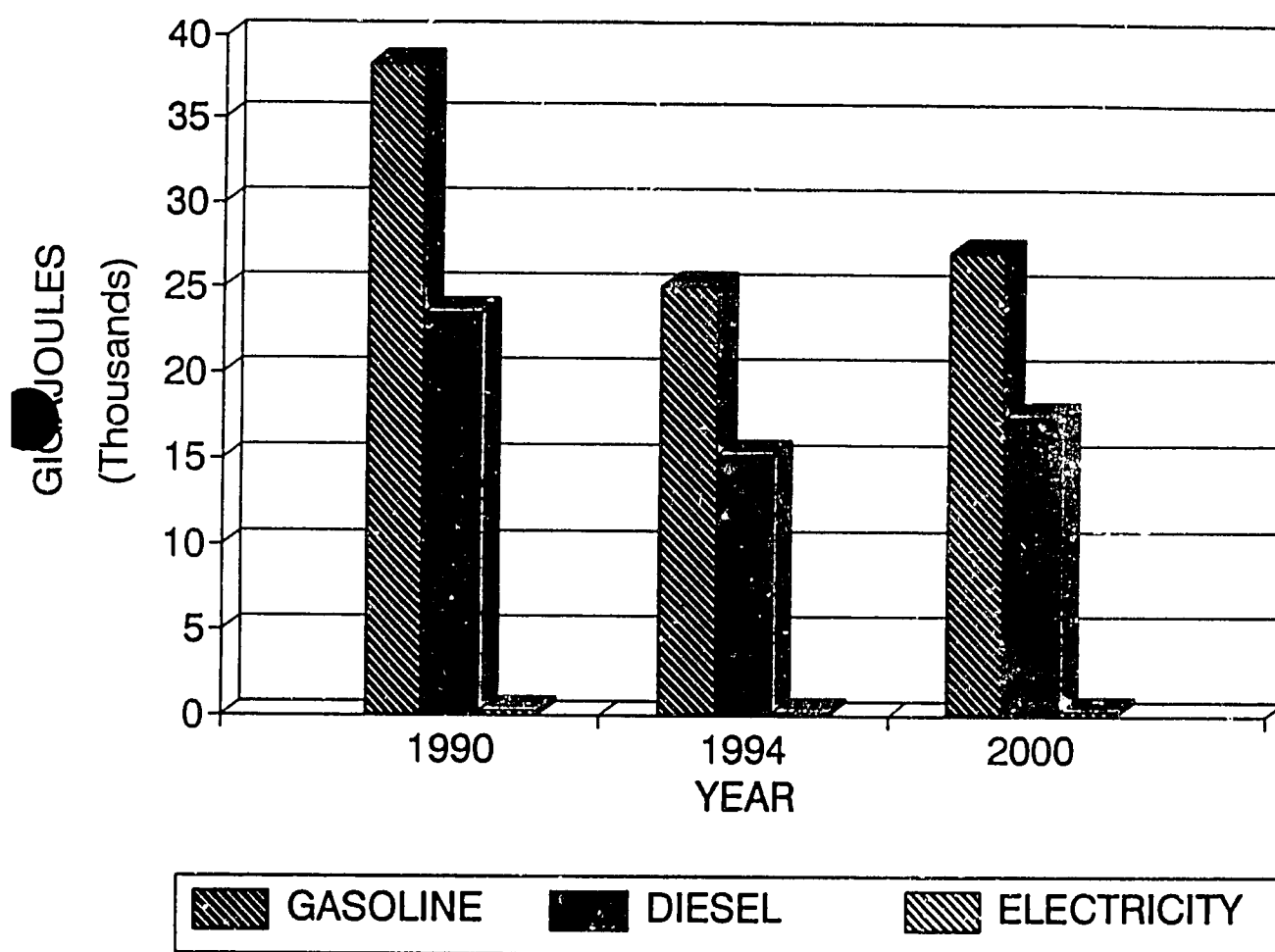


SCENARIO 1ALT

TRANSP SECTOR ENERGY INTENSITY

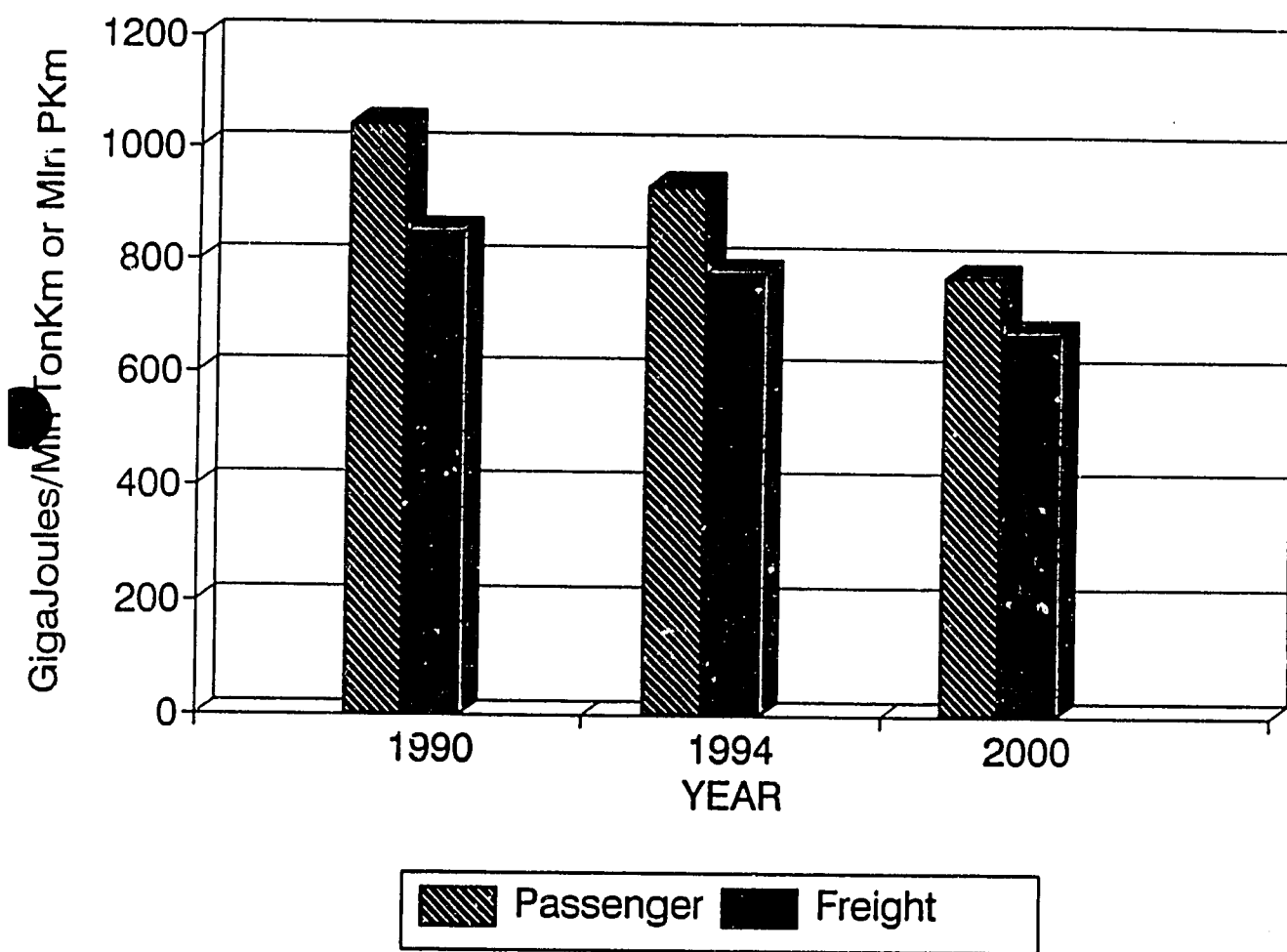


NET ENERGY USE BY FUEL TYPE



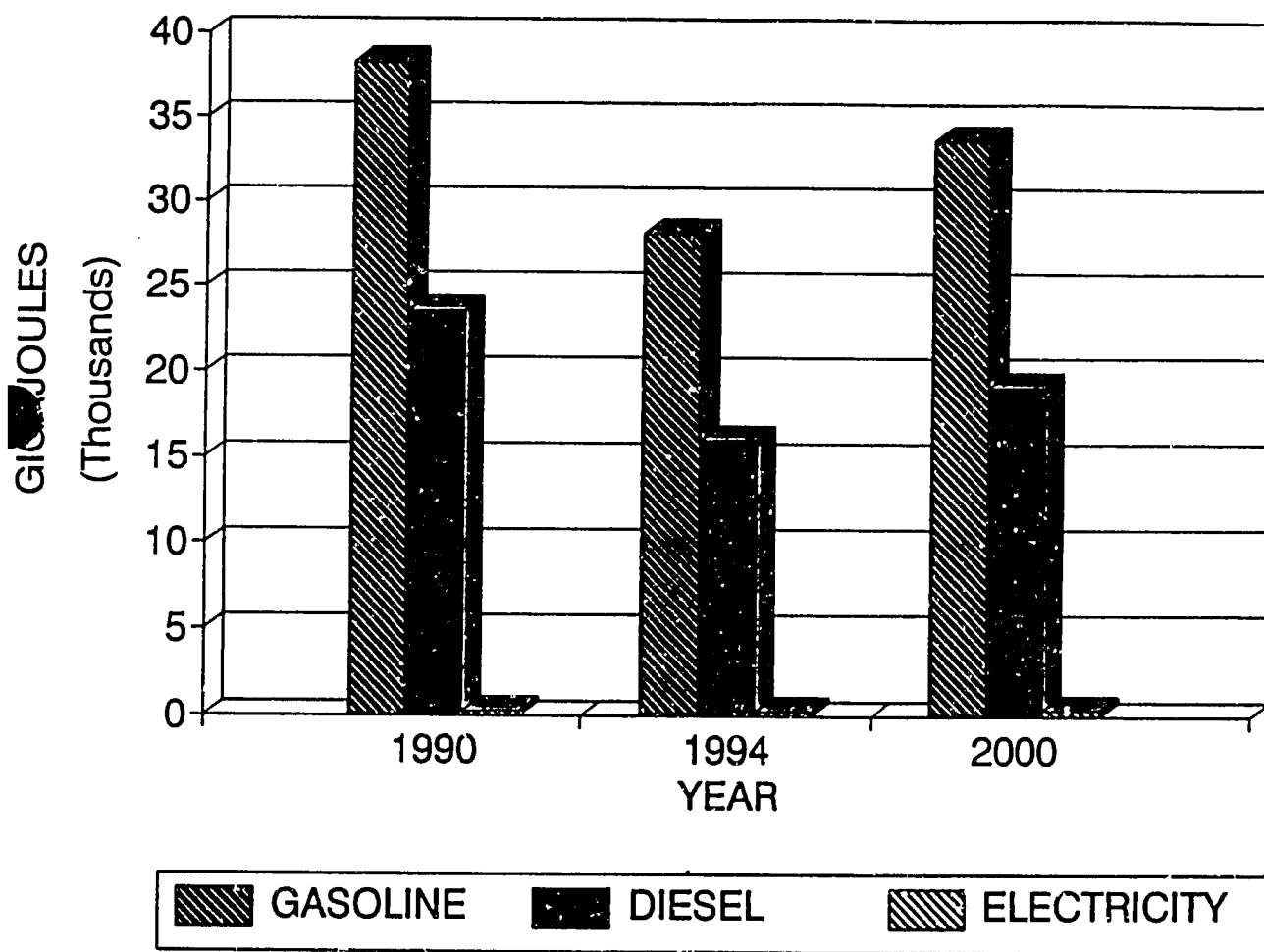
SCENARIO 2

TRANSP SECTOR ENERGY INTENSITY



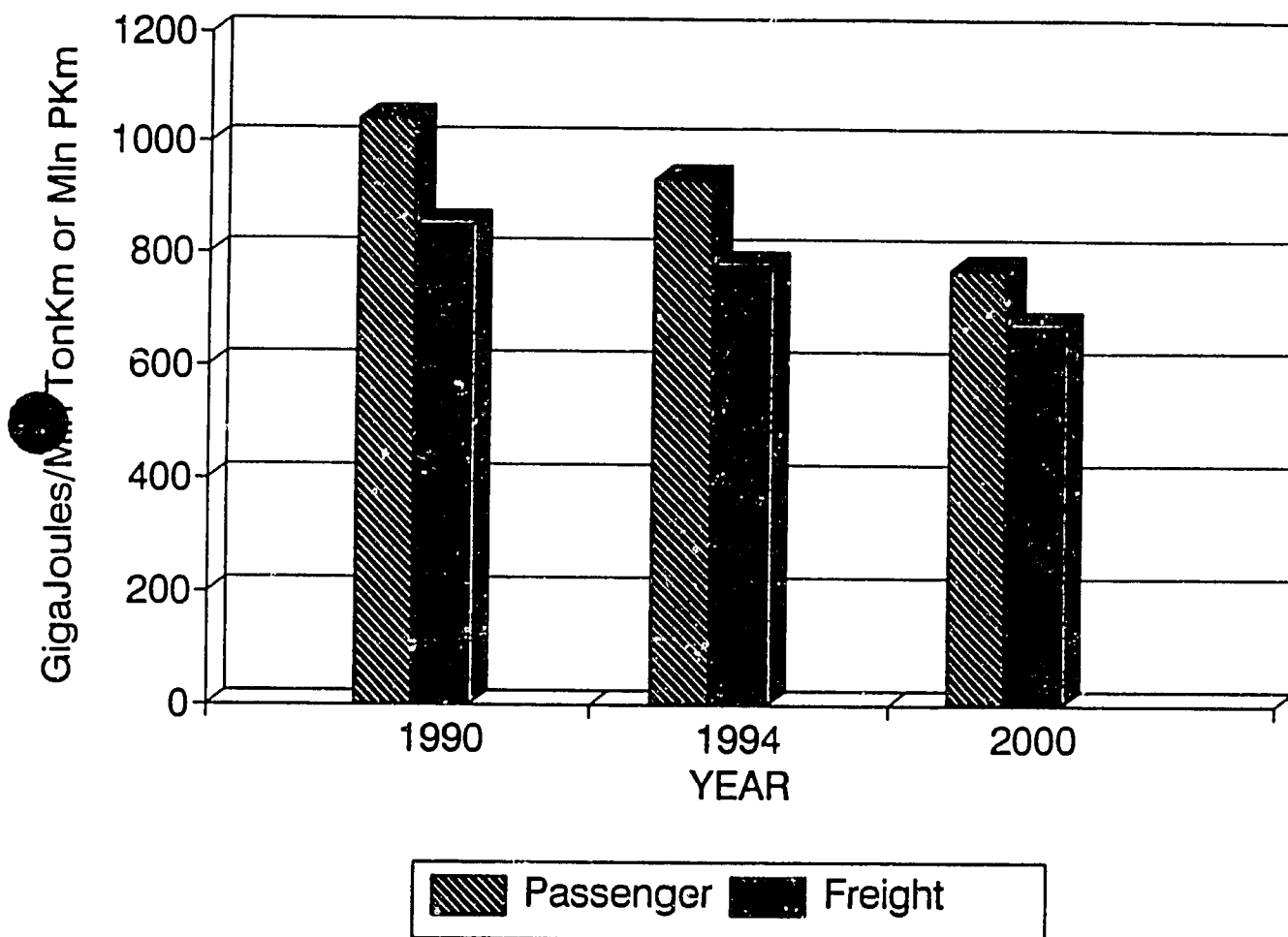
SCENARIO 2

NET ENERGY USE BY FUEL TYPE



SCENARIO 3

TRANSP SECTOR ENERGY INTENSITY



SCENARIO 3

**INDUSTRIAL, AGRICULTURAL AND CONSTRUCTION
SECTOR ENERGY DEMAND SCENARIOS**

USING THE

RMA INDUSTRIAL ENERGY DEMAND MODEL

**A PORTION OF THE
ENERGY PRICE REFORM WORKSHOP
APRIL 30 - MAY 7, 1992**

Presented By:

Resource Management Associates of Madison, Inc.

In Cooperation with:

**Tellus Institute
and
Energy Price Reform Working Group
Government of Lithuania**

**U.S. EMERGENCY ENERGY PROGRAM
United States Agency for International Development
Contract No. EUR-0015-C-00-1006-00**



**Resource Management Associates of Madison, Inc.
Madison, Wisconsin, U.S.A.**

DATA INITIALIZATION MODULE*

CASE TITLE: SCENARIO 2

Base year 1990 Projected years (Can specify up to 5 future years)
1992 1994 1996 1998 2000

1990 ENERGY CONSUMPTION BY SECTOR AND FUEL

	Electric (GWH)	Heat (TJ)	Gas (Ktce)	Fuel Oil (Ktce)	Other	Other	Other
Agriculture	2700	660	199	663	0.00	0.00	0.00
Food & Beverage.	480	630	313	240	0.00	0.00	0.00
Metal Prds & Machinery	1250	550	325	190	0.00	0.00	0.00
Construction & NF Min Prod	1160	710	420	1172	0.00	0.00	0.00
Light Industry	610	320	142	90	0.00	0.00	0.00
Wood & Paper	560	440	207	171	0.00	0.00	0.00
Chemical	1190	700	383	236	0.00	0.00	0.00
Petroleum & Refining	460	410	0	1034	0.00	0.00	0.00
Other	210	360	86	23	0.00	0.00	0.00
TOTAL	8620.0	4780.0	2075.00	3819.00	0.00	0.00	0.0

1990 ENERGY PRICES (Roubles/quantity of fuel)

Electric (R/KWH)	Heat (R/GJ)	Gas (R/m ³)	Fuel Oil (R/tonne)	Other	Other	Other
0.03	1.99	0.03	24.50			

1990 TOTAL OUTPUT (E6 R) PROJECTED ANNUAL EXOGENOUS GROWTH
1991-92 1993-94 1995-96 1997-98 1999-2000

Agriculture	6335	-10%	0%	5%	5%	5%
Food & Beverage.	3580	-10%	0%	5%	5%	5%
Metal Prds & Machinery	3444	-15%	-10%	0%	0%	0%
Construction & NF Min Prod	3394	-10%	-5%	0%	5%	5%
Light Industry	2865	-10%	-5%	0%	7%	10%
Wood & Paper	691	-10%	0%	3%	3%	3%
Chemical	485	-10%	0%	5%	5%	5%
Petroleum & Refining	428	-20%	-20%	15%	5%	3%
Other	615	-10%	0%	5%	5%	5%
TOTAL	21837					

(To Return to Macro Menu, press "Alt-M")

FUEL CONVERSION FACTORS TO:

	Electric (TJ/GWH)	Heat (TJ/TJ)	Gas (TJ/ktce)	Fuel Oil (TJ/ktce)	Other	Other	Other
Units:							
Value:	3.60	1.00	29.30	29.30			

 * PRICING INPUT MODULE *

CASE TITLE: SCENARIO 2

TARGET INCREASES IN REAL ENERGY PRICES (in Roubles):

	Electric (R/KWH)	Heat (R/GJ)	Gas (R/m ³)	Fuel Oil (R/tonne)
1992	0.08	10.51	0.02	317.00
1994	0.11	15.13	0.03	535.73
1996	0.11	15.13	0.03	535.73
1998	0.11	15.13	0.03	535.73
2000	0.11	15.13	0.03	535.73

ENERGY PRICE RESPONSE FOR EACH SUBSECTOR AND FUEL

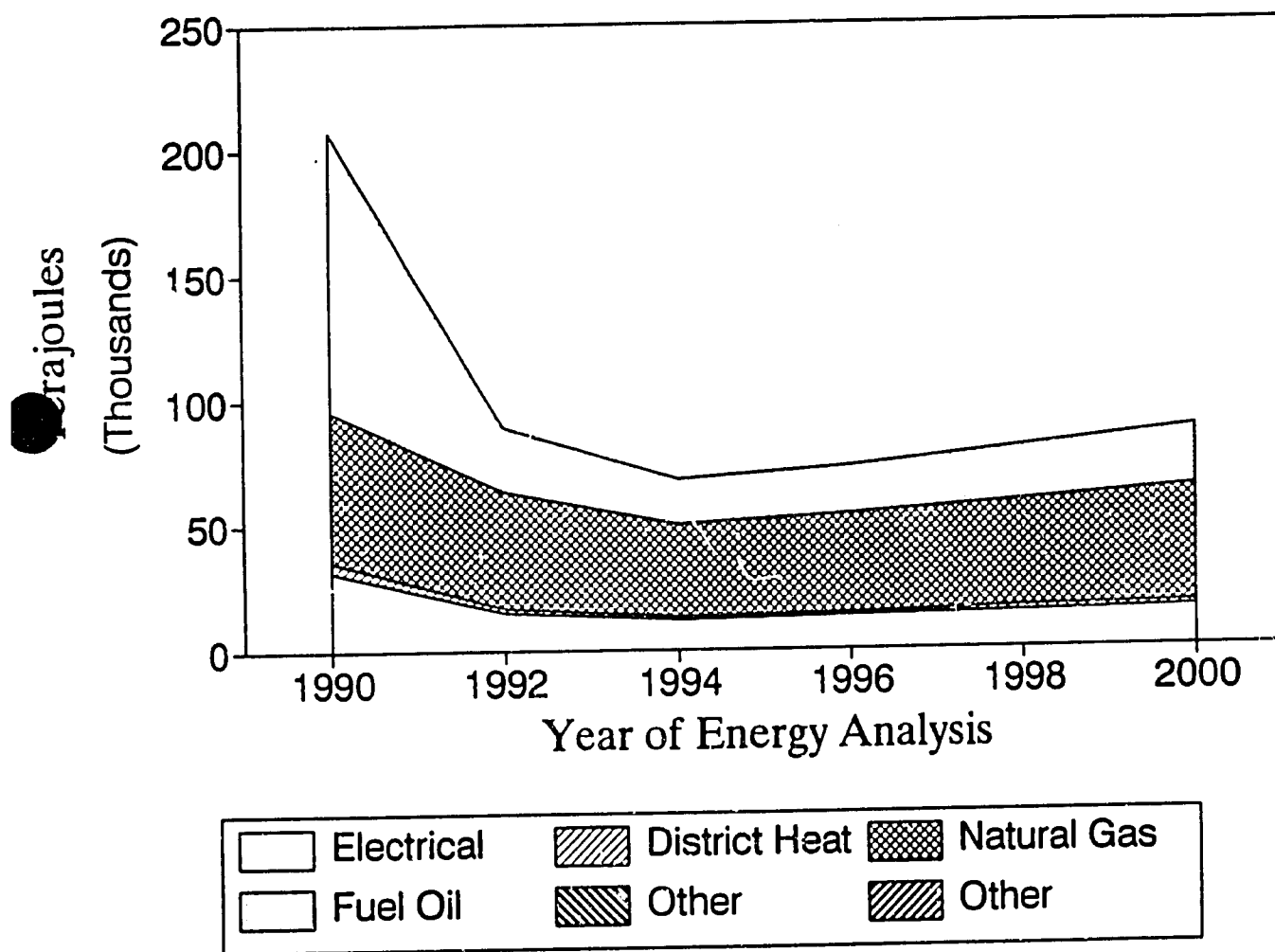
	Electric	Heat	Gas	Fuel Oil
Agriculture	-0.20	-0.20	-0.20	-0.20
Food & Beverage.	-0.30	-0.30	-0.30	-0.30
Metal Prds & Machinery	-0.40	-0.40	-0.40	-0.40
Construction & NF Min Prod	-0.40	-0.40	-0.40	-0.40
Light Industry	-0.20	-0.20	-0.20	-0.20
Wood & Paper	-0.30	-0.30	-0.30	-0.30
Chemical	-0.30	-0.30	-0.30	-0.30
Petroleum & Refining	-0.40	-0.40	-0.40	-0.40
Other	-0.10	-0.10	-0.10	-0.10

OUTPUT PRICE RESPONSE FOR EACH SUBSECTOR AND FUEL

	Electric	Heat	Gas	Fuel Oil
Agriculture	-0.20	-0.20	-0.20	-0.20
Food & Beverage.	-0.10	-0.10	-0.10	-0.10
Metal Prds & Machinery	0.00	0.00	0.00	0.00
Construction & NF Min Prod	-0.20	-0.20	-0.20	-0.20
Light Industry	0.00	0.00	0.00	0.00
Wood & Paper	-0.20	-0.20	-0.20	-0.20
Chemical	-0.50	-0.50	-0.30	-0.50
Petroleum & Refining	-0.50	-0.50	-0.30	-0.50
Other	0.00	0.00	0.00	0.00

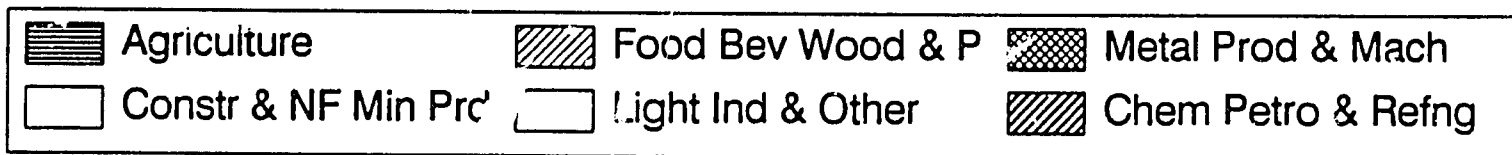
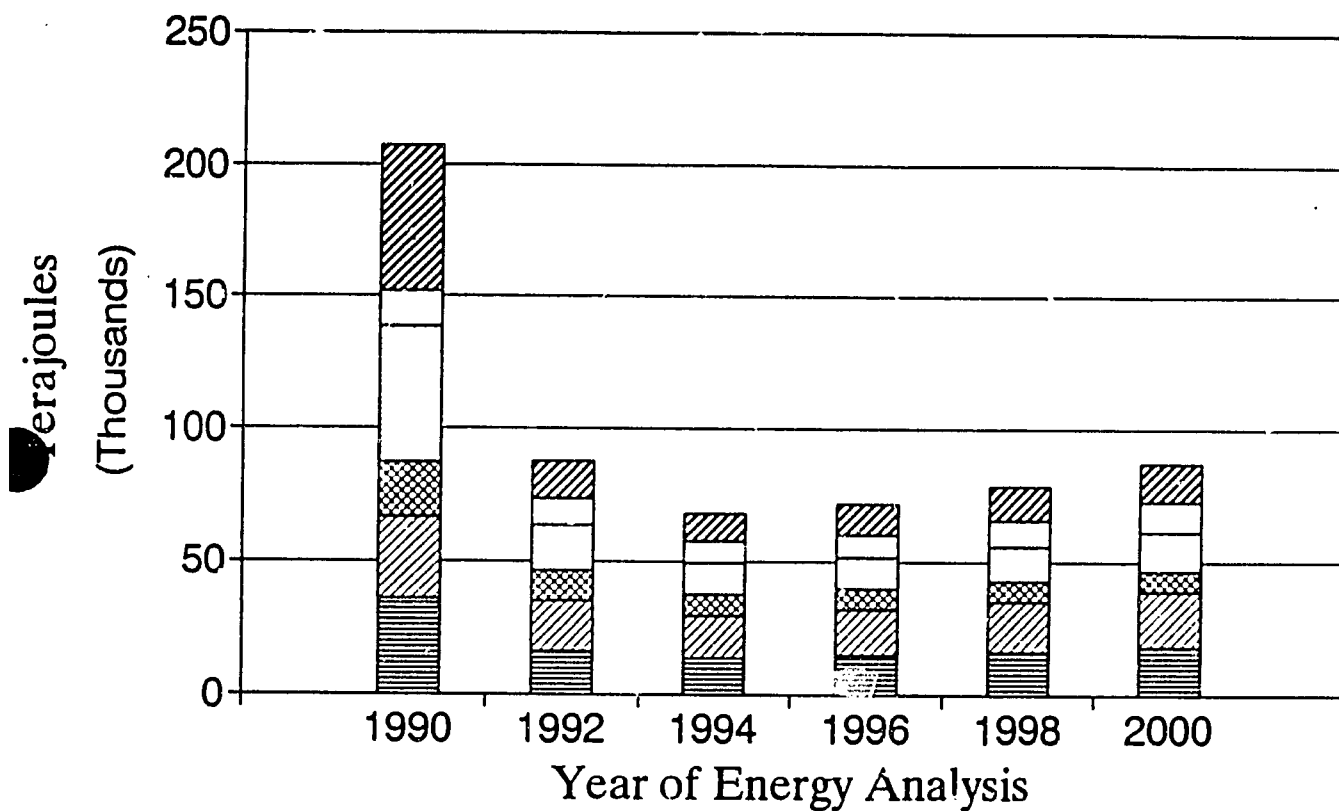
95

Indus Agri & Constr Fuel Use By fuel type



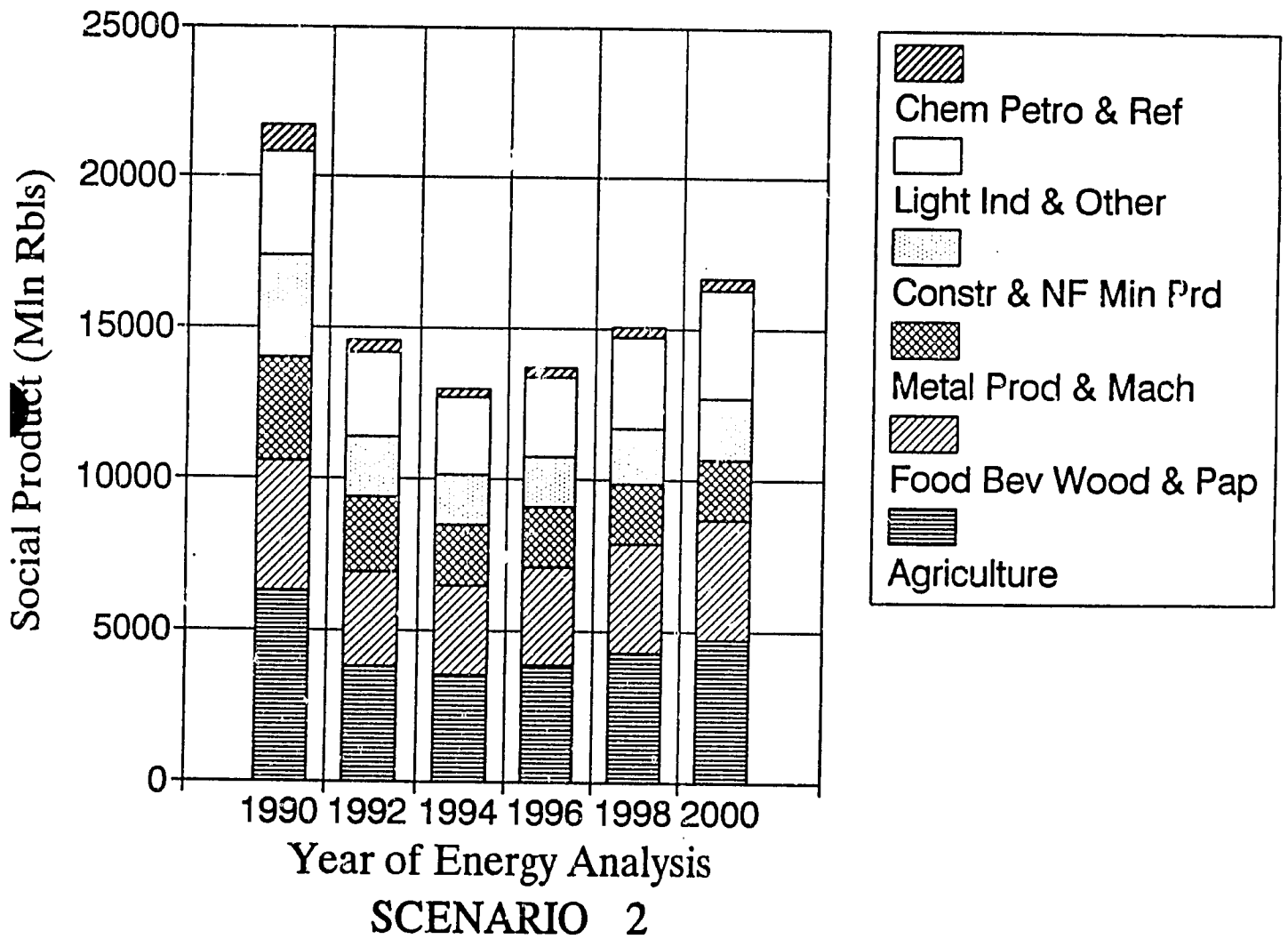
SCENARIO 2

Energy Consumption Indus Agri & Constr Sectors

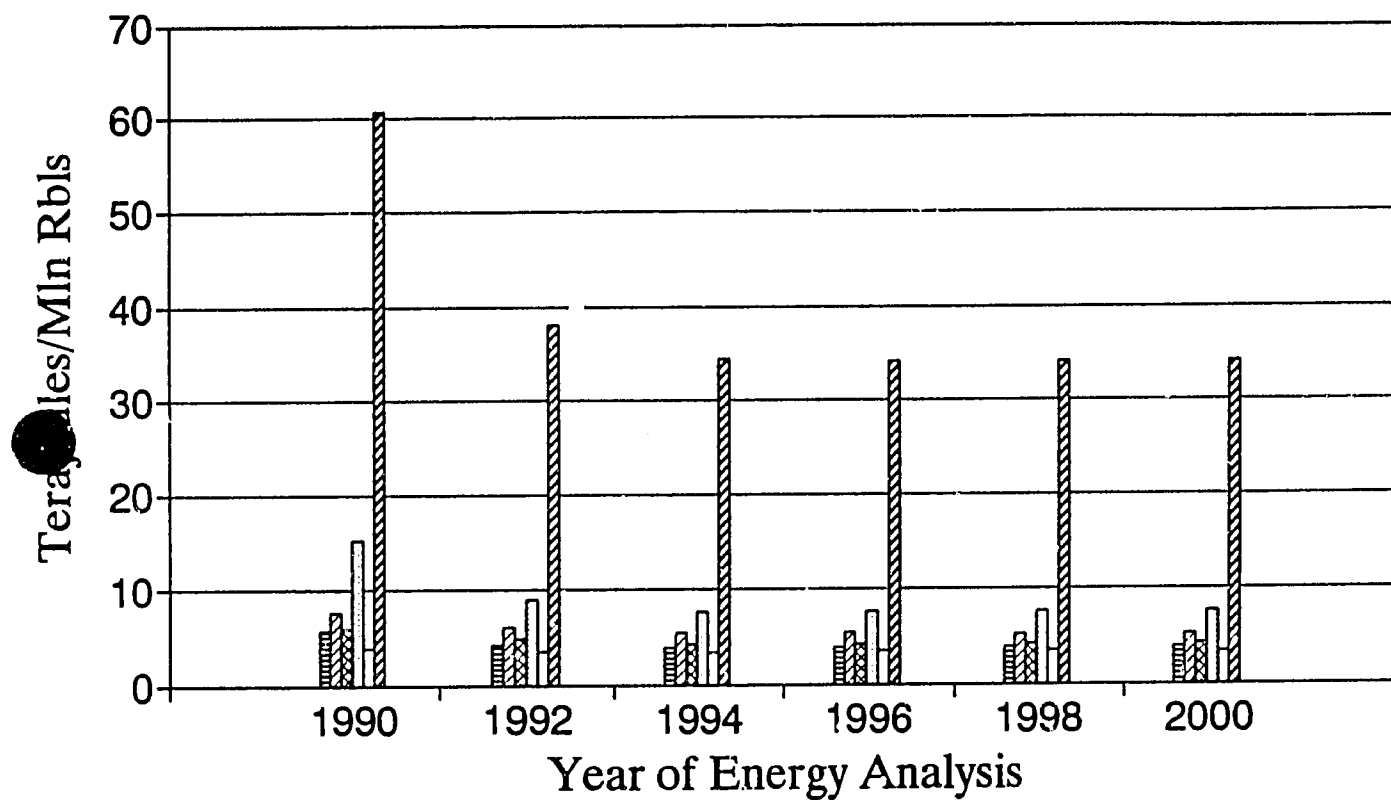


SCENARIO 2

Social Product of Industrial Agri & Construction Sectors



Energy Intensity Indus Agri & Constr Sectors



SCENARIO 2

DATA INITIALIZATION MODULE*

CASE TITLE: SCENARIO 3

Base year Projected years (Can specify up to 5 future years)

1990 1992 1994 1996 1998 2000

1990 ENERGY CONSUMPTION BY SECTOR AND FUEL

	Electric (GWH)	Heat (TJ)	Gas (Ktce)	Fuel Oil (Ktce)	Other	Other	Other
Agriculture	2700	660	199	663	0.00	0.00	0.00
Food & Beverage.	480	630	313	240	0.00	0.00	0.00
Metal Prds & Machinery	1250	550	325	190	0.00	0.00	0.00
Construction & NF Min Prod	1160	710	420	1172	0.00	0.00	0.00
Light Industry	610	320	142	90	0.00	0.00	0.00
Wood & Paper	560	440	207	171	0.00	0.00	0.00
Chemical	1190	700	383	236	0.00	0.00	0.00
Petroleum & Refining	460	410	0	1034			
Other	210	360	86	23	0.00	0.00	0.00
TOTAL	8620.0	4780.0	2075.00	3819.00	0.00	0.00	0.0

1990 ENERGY PRICES (Roubles/quantity of fuel)

	Electric (R/KWH)	Heat (R/GJ)	Gas (R/m ^ 3)	Fuel Oil (R/tonne)	Other	Other	Other
	0.03	1.99	0.03	24.50			

1990 TOTAL OUTPUT
(E6 R)

PROJECTED ANNUAL EXOGENOUS GROW
1991-92 1993-94 1995-96 1997-98 1999-200

Agriculture	6335	-10%	0%	5%	5%	5%
Food & Beverage.	3580	-10%	0%	5%	5%	5%
Metal Prds & Machinery	3444	-15%	-10%	0%	0%	0%
Construction & NF Min Prod	3394	-10%	-5%	0%	5%	5%
Light Industry	2865	-10%	-5%	0%	7%	10%
Wood & Paper	691	-10%	0%	3%	3%	3%
Chemical	485	-10%	0%	5%	5%	5%
Petroleum & Refining	428	-20%	-20%	15%	5%	3%
Other	615	-10%	0%	5%	5%	5%

TOTAL 21837

 * PRICING INPUT MODULE *

CASE TITLE: SCENARIO 3

TARGET INCREASES IN REAL ENERGY PRICES (in Roubles):

	Electric (R/KWH)	Heat (R/GJ)	Gas (R/m ³)	Fuel Oil (R/tonne)	Other 0
1992	0.08	10.51	0.02	317.00	
1994	0.17	23.65	0.04	713.25	
1996	0.17	23.65	0.04	713.25	
1998	0.17	23.65	0.04	713.25	
2000	0.17	23.65	0.04	713.25	

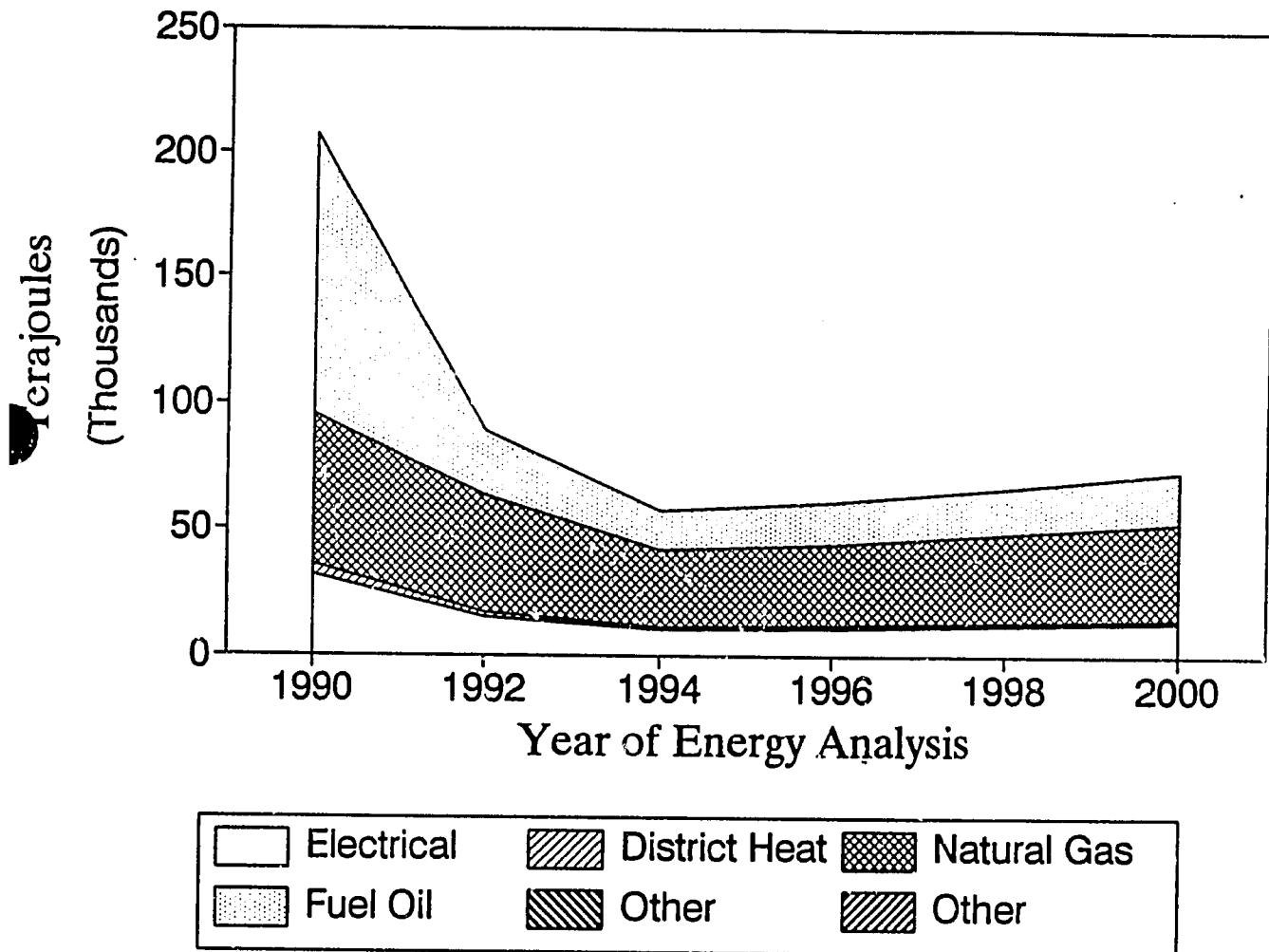
ENERGY PRICE RESPONSE FOR EACH SUBSECTOR AND FUEL TYPE:

	Electric	Heat	Gas	Fuel Oil	Other
Agriculture	-0.20	-0.20	-0.20	-0.20	
Food & Beverage.	-0.30	-0.30	-0.30	-0.30	
Metal Prds & Machinery	-0.40	-0.40	-0.40	-0.40	
Construction & NF Min Prod	-0.40	-0.40	-0.40	-0.40	
Light Industry	-0.20	-0.20	-0.20	-0.20	
Wood & Paper	-0.30	-0.30	-0.30	-0.30	
Chemical	-0.30	-0.30	-0.30	-0.30	
Petroleum & Refining	-0.40	-0.40	-0.40	-0.40	
Other	-0.10	-0.10	-0.10	-0.10	

OUTPUT PRICE RESPONSE FOR EACH SUBSECTOR AND FUEL TYPE:

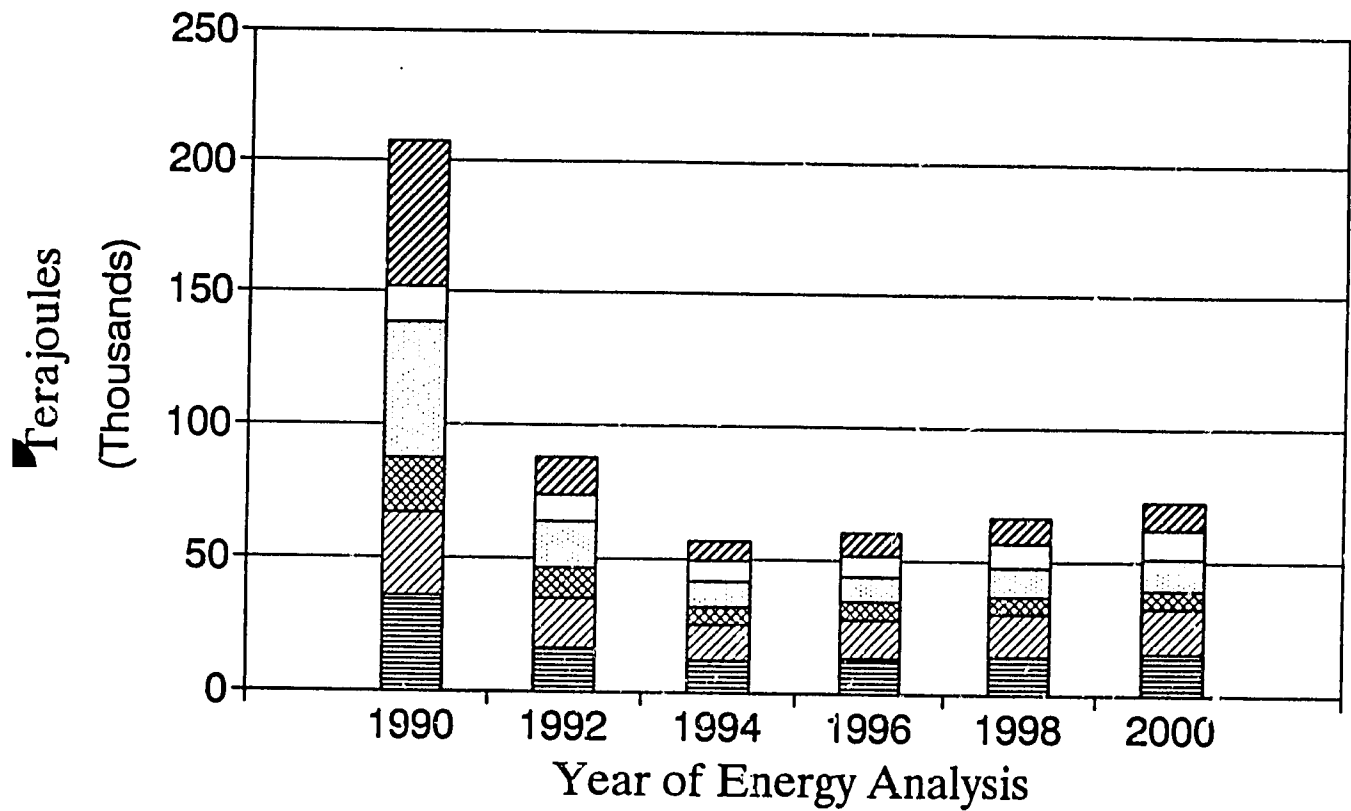
	Electric	Heat	Gas	Fuel Oil	Other
Agriculture	-0.20	-0.20	-0.20	-0.20	
Food & Beverage.	-0.10	-0.10	-0.10	-0.10	
Metal Prds & Machinery	0.00	0.00	0.00	0.00	
Construction & NF Min Prod	-0.20	-0.20	-0.20	-0.20	
Light Industry	0.00	0.00	0.00	0.00	
Wood & Paper	-0.20	-0.20	-0.20	-0.20	
Chemical	-0.50	-0.50	-0.30	-0.50	
Petroleum & Refining	-0.50	-0.50	-0.30	-0.50	
Other	0.00	0.00	0.00	0.00	

Indus Agri & Constr Fuel Use By fuel type



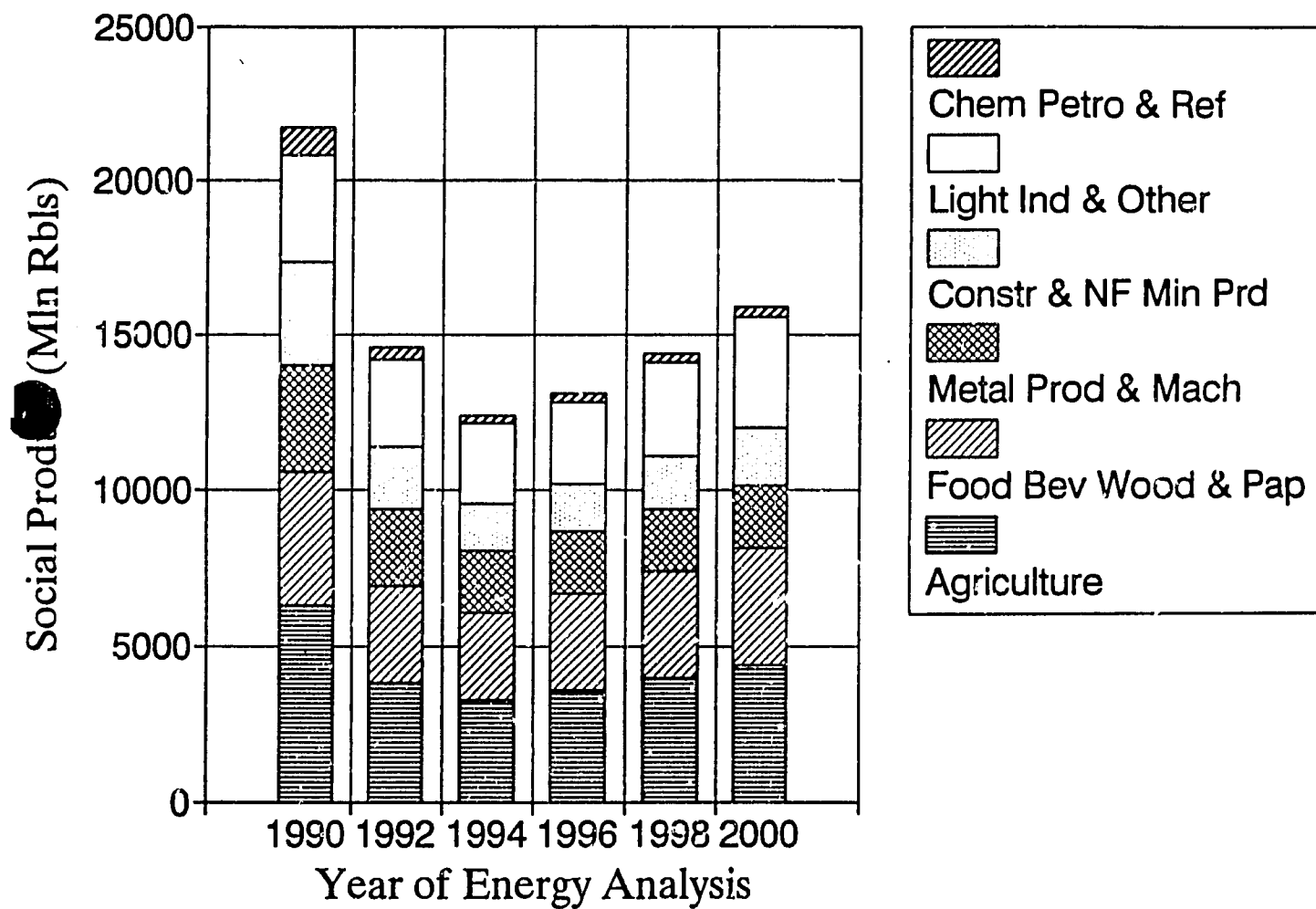
SCENARIO 3

Energy Consumption Indus Agri & Constr Sectors

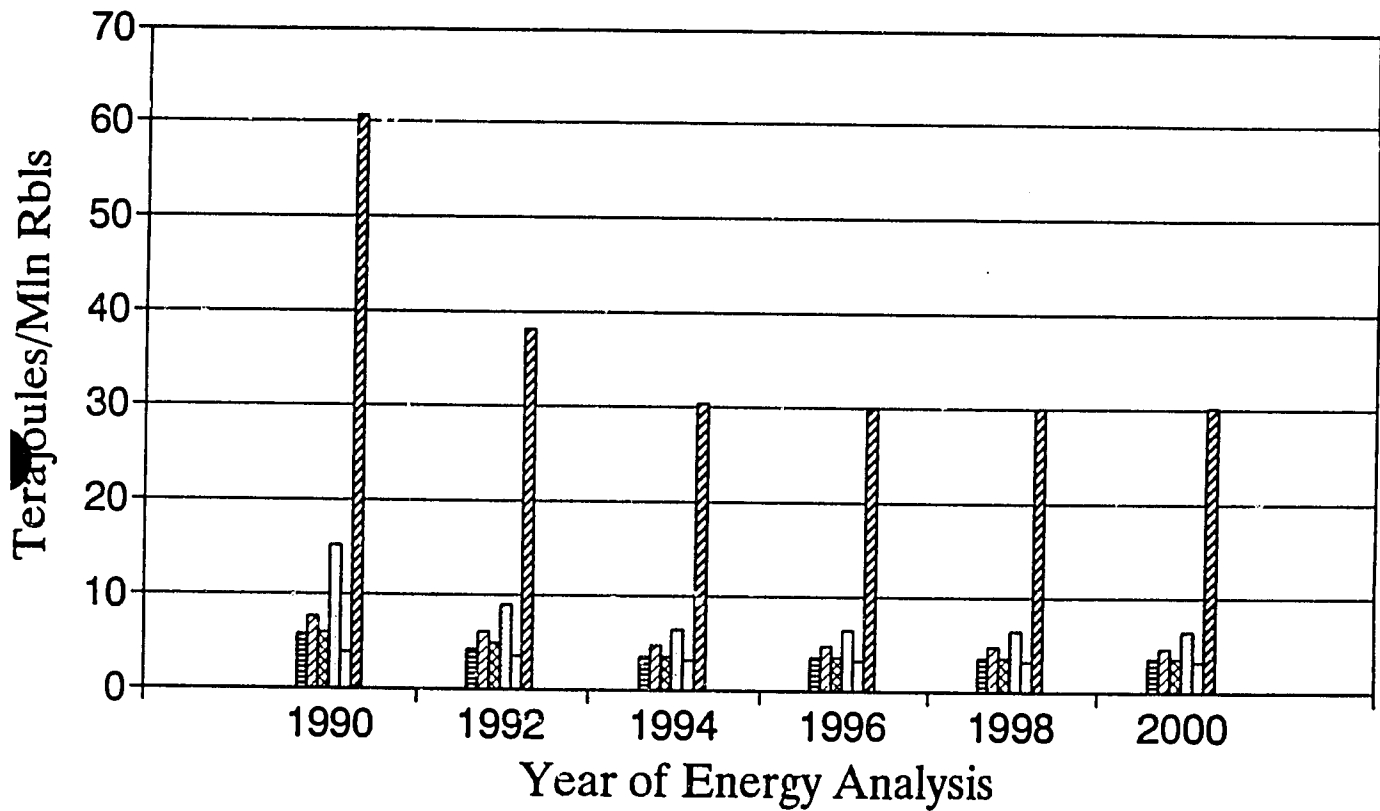


SCENARIO 3

Social Product of Industrial Agri & Construction Sectors

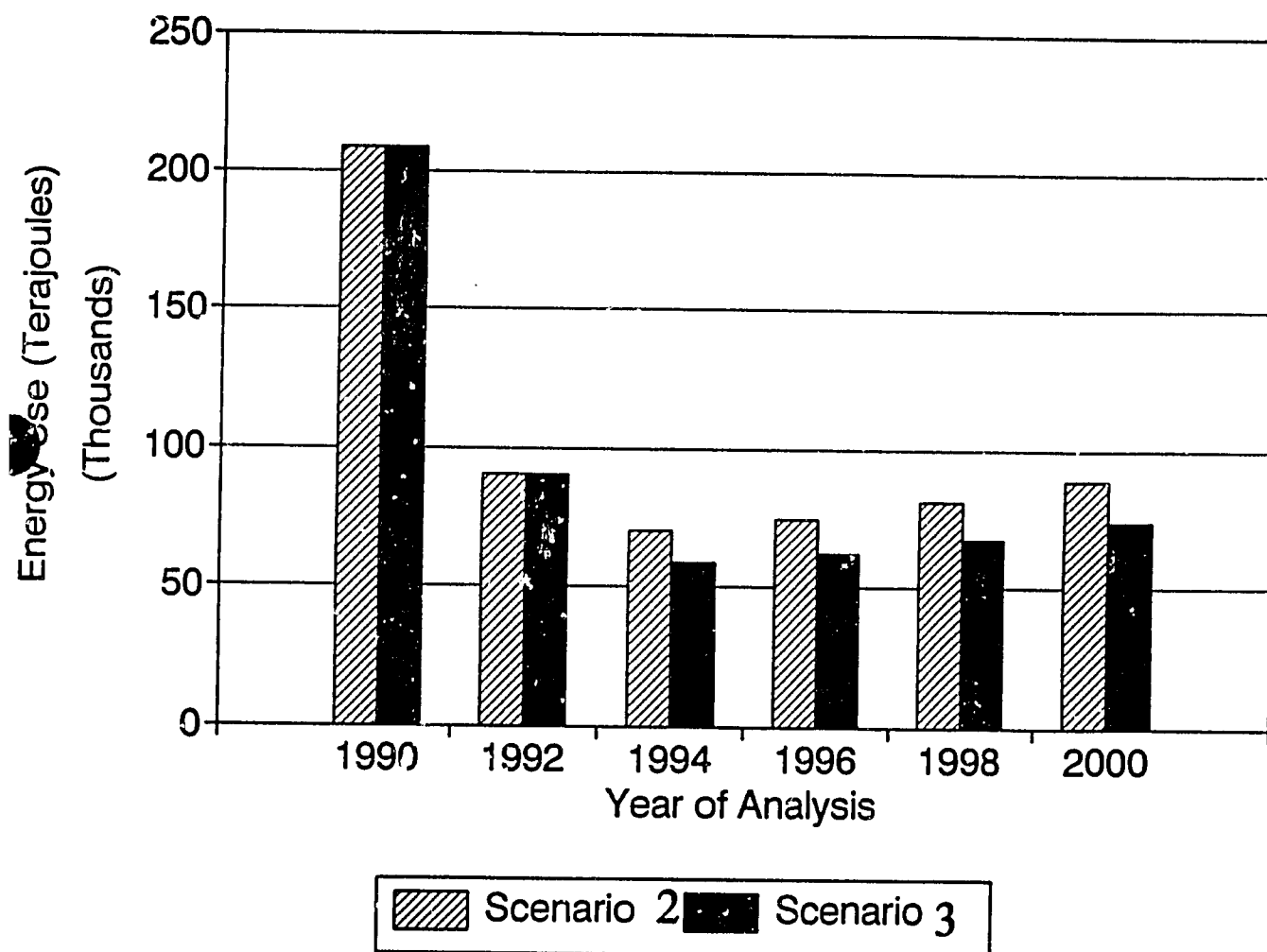


Energy Intensity Indus Agri & Constr Sectors

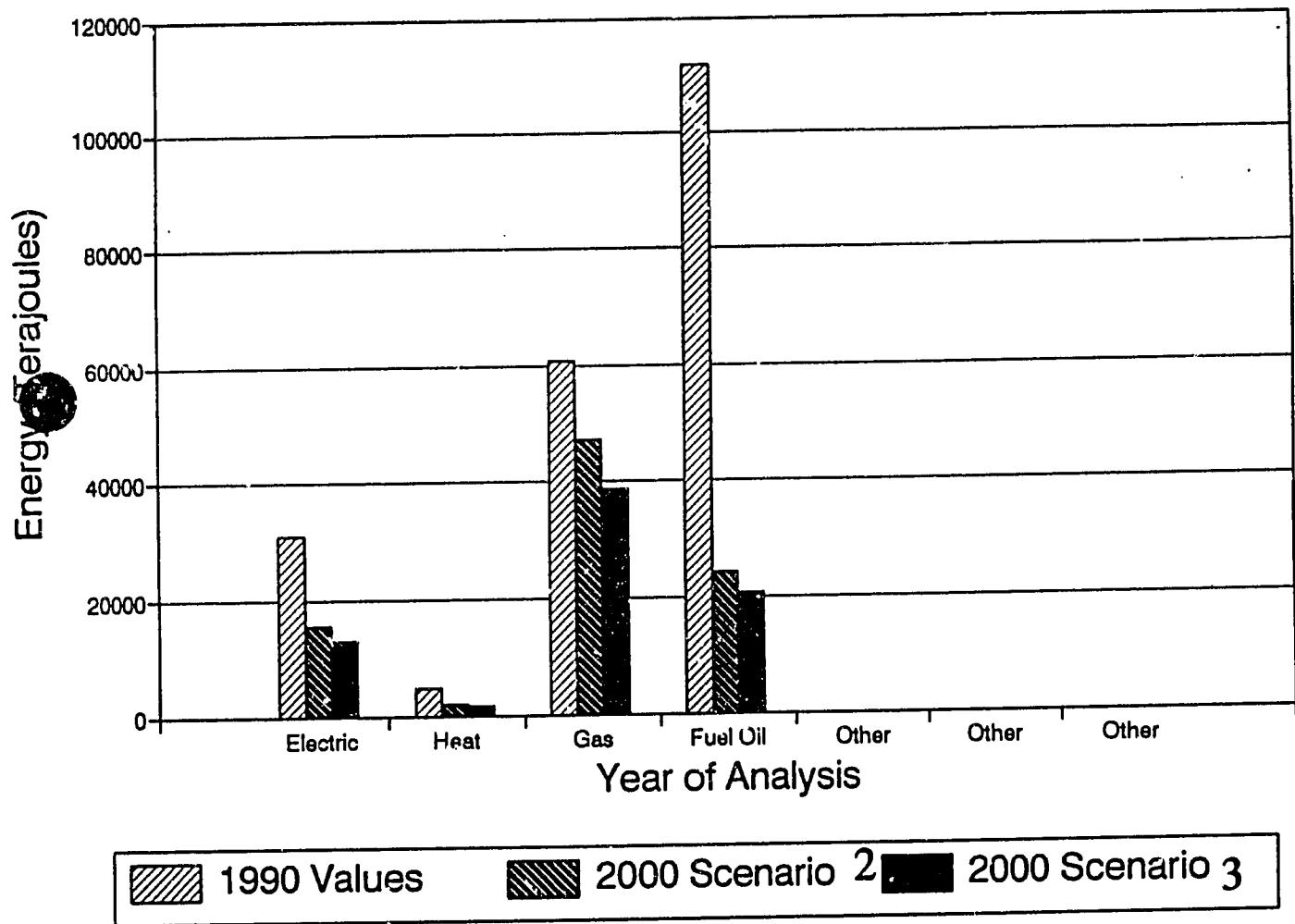


SCENARIO 3

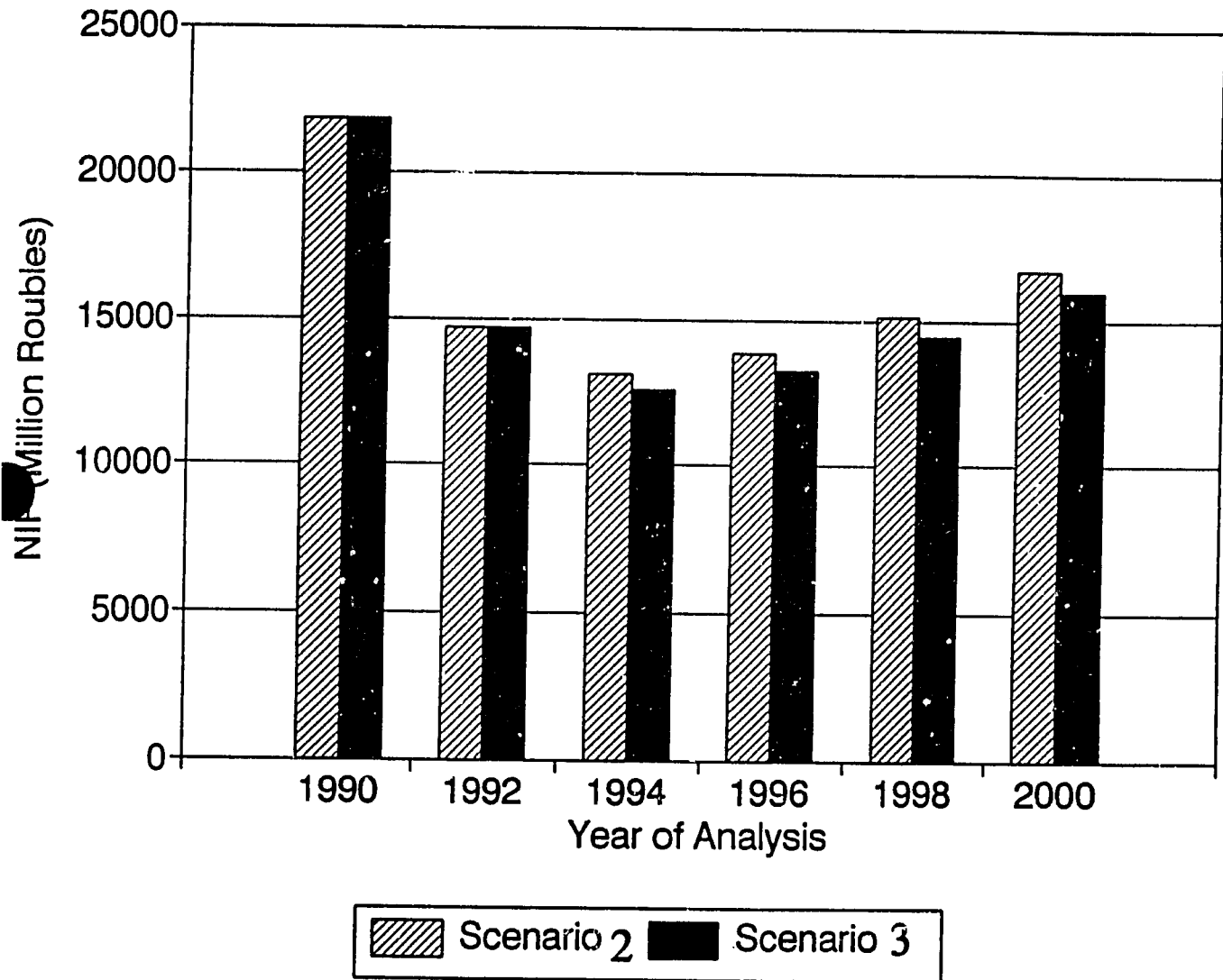
Energy Use in Industrial Sector



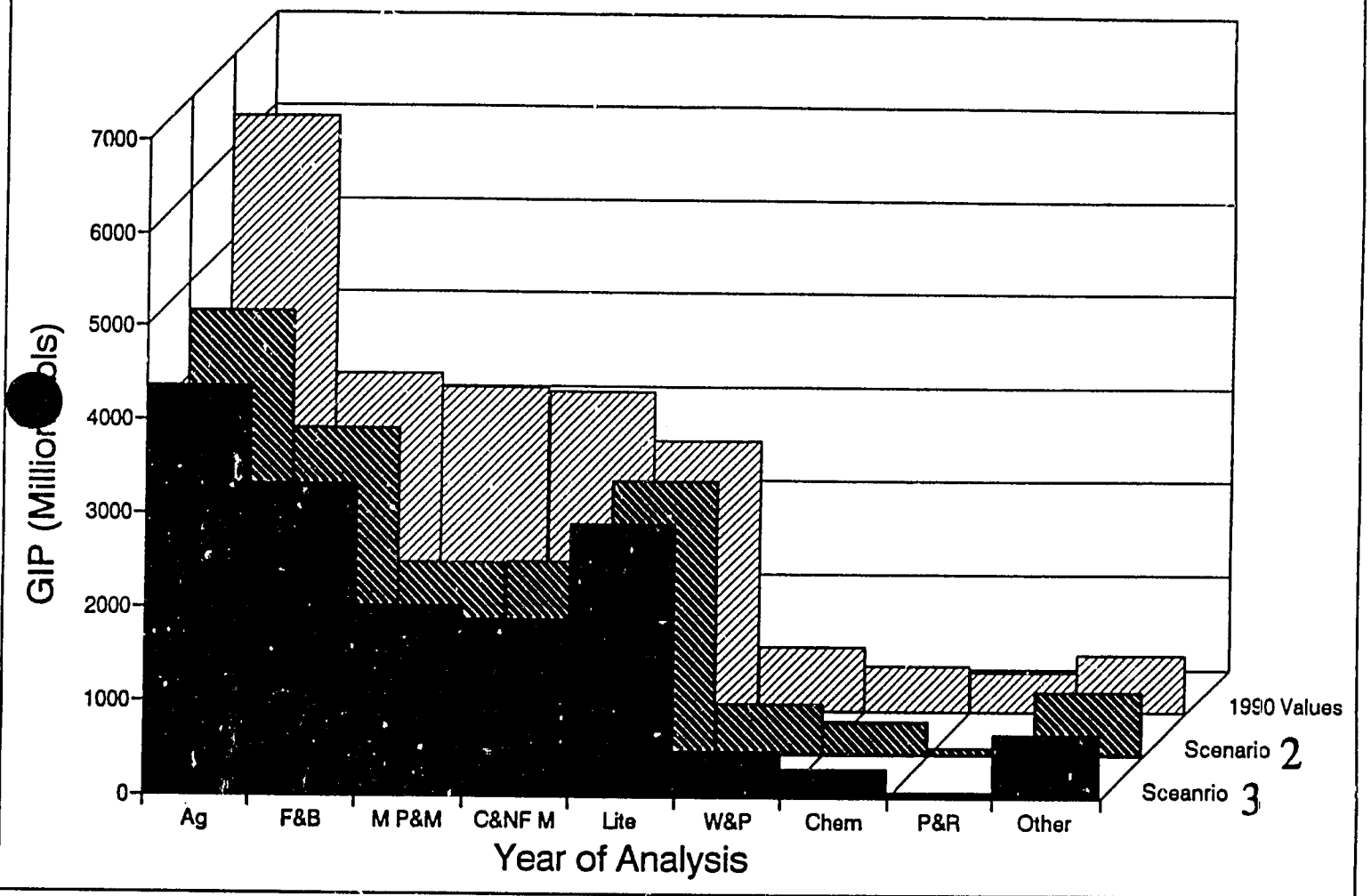
Energy Use by Fuel Type in the Industrial Sector



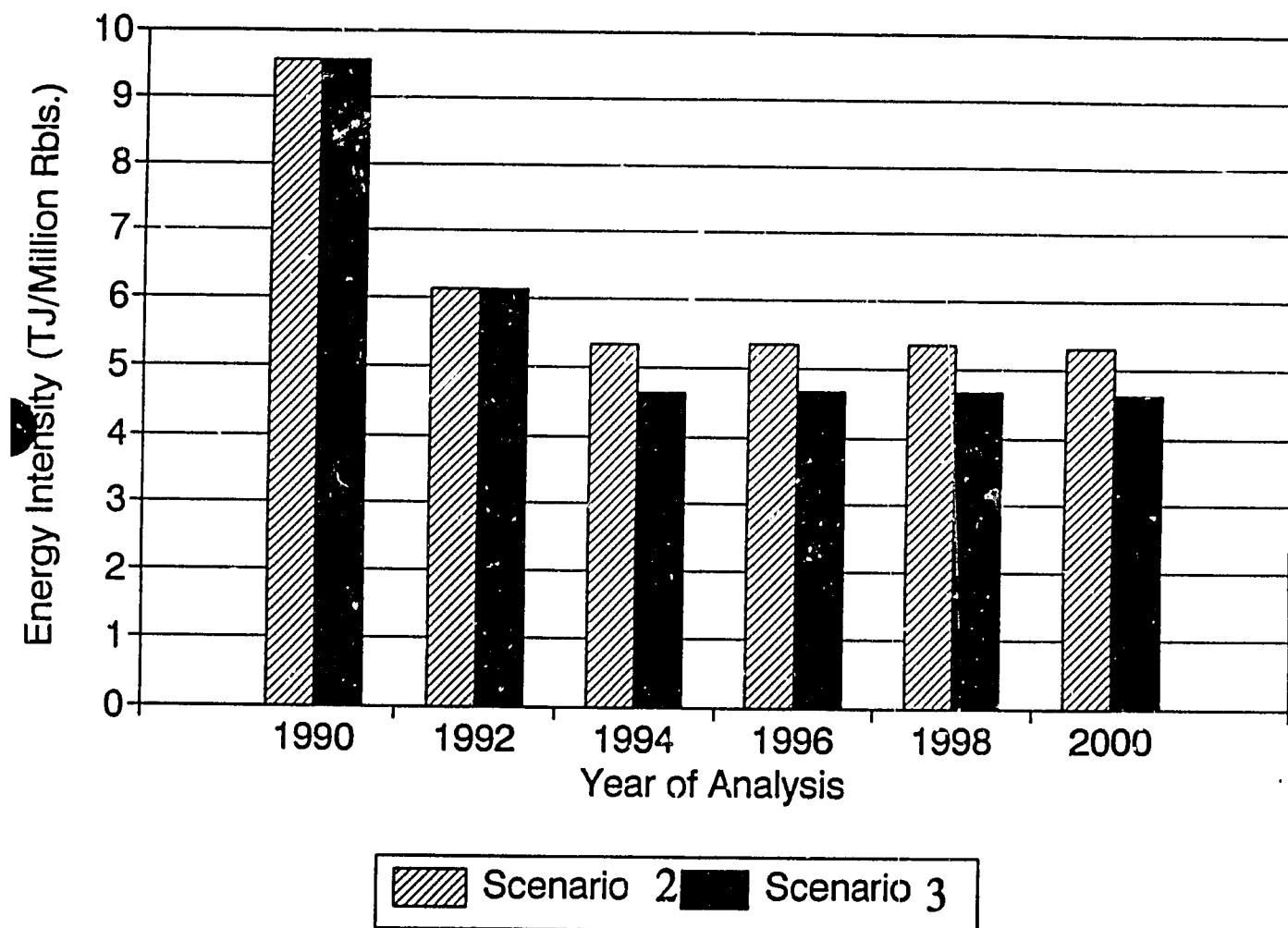
Net Industrial Product



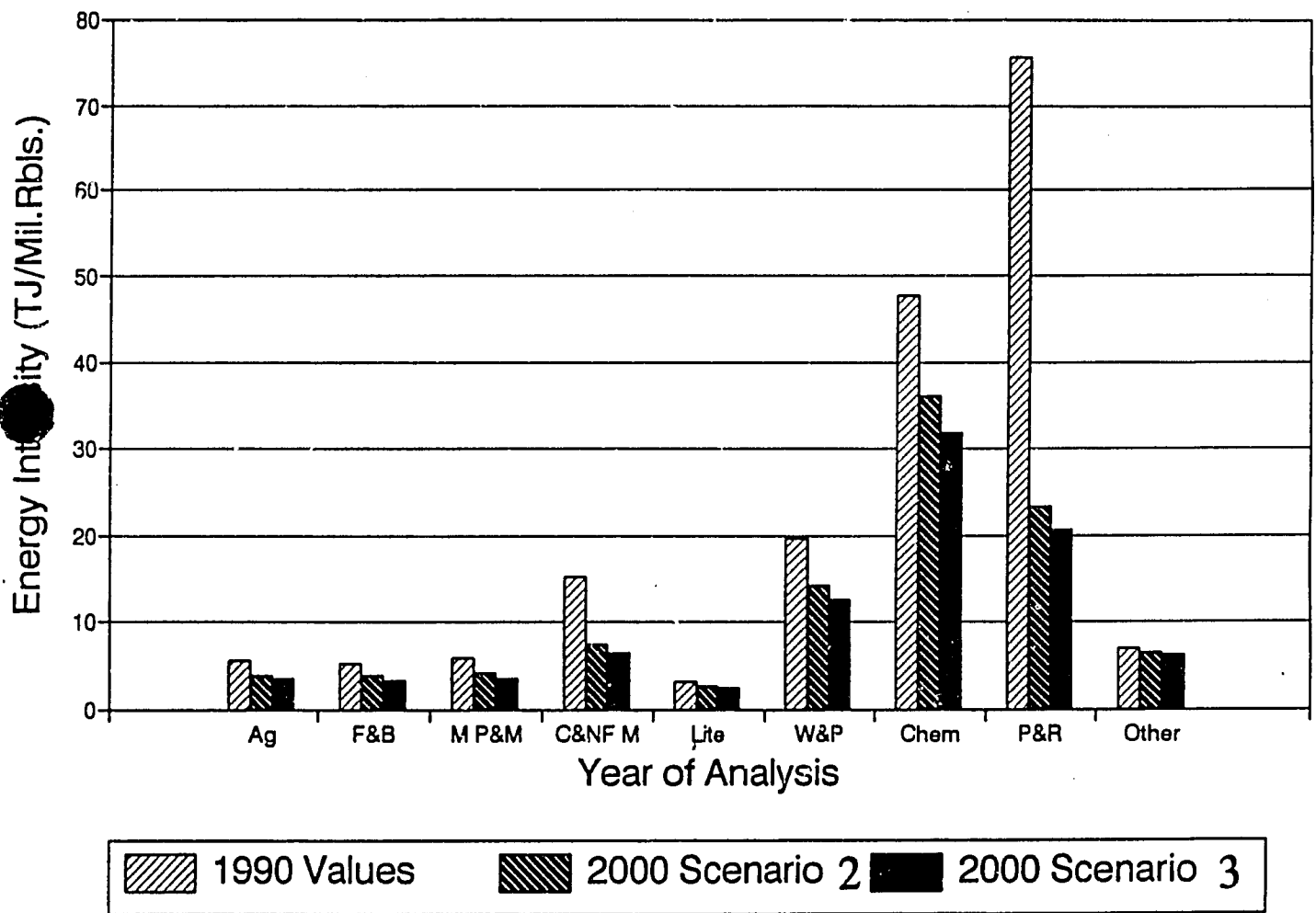
Net Industrial Product By Subsector



Energy Intensities of the Industrial Sector



Energy Intensity by Industrial Subsector



ESTIMATED PRICE ELASTICITY OF DEMAND
used in Romanian model

Agriculture
Food & Beverage
Metal Prds & Machinery
Construction & NF Min Prod
Light Industry
Wood & Paper
Chemical
Petroleum & Refining
Other

Price Elasticity of Demand				
Oil Prod.	Nat Gas	Elec.	Heat	Other
-0.4	-0.4	-0.3	-0.3	
-0.4	-0.4	-0.3	-0.3	
-0.2	-0.2	-0.2	-0.2	
-0.2	-0.3	-0.2	-0.2	
-0.25	-0.25	-0.25	-0.25	
-0.4	-0.4	-0.3	-0.3	
-0.4	-0.5	-0.35	-0.35	
-0.4	-0.5	-0.35	-0.35	
-0.25	-0.25	-0.25	-0.25	

ESTIMATED PRICE ELASTICITY OF OUTPUT
used in Romanian model

Agriculture
Food & Beverage
Metal Products & Machinery
Construction & NF Min Prod
Light Industry
Wood & Paper
Chemical
Petroleum & Refining
Other

Price Elasticity of Output				
Oil Prod.	Nat Gas	Elec.	Heat	Other
0	0	0	0	
0	0	0	0	
0	0	0	0	
0	0	0	0	
0	0	0	0	
0	0	0	0	
-0.5	-0.5	-0.4	-0.4	
-0.5	-0.5	-0.4	-0.4	
0	0	0	0	

ESTIMATED PRICE ELASTICITY OF DEMAND

used in Czechoslovakian model

Agriculture
Food & Beverage
Metal Prds & Machinery
Construction & NF Min Prod
Light Industry
Wood & Paper
Chemical
Petroleum & Refining
Other

Price Elasticity of Demand				
Oil Prod.	Nat Gas	Elec.	Heat	Other
-0.25	-0.25	-0.25	-0.25	
-0.25	-0.25	-0.25	-0.25	
-0.11	-0.1	-0.22	-0.1	
-0.22	-0.22	-0.22	-0.22	
-0.2	-0.2	-0.2	-0.2	
-0.16	-0.16	-0.16	-0.16	
-0.23	-0.23	-0.23	-0.23	
-0.23	-0.23	-0.23	-0.23	
-0.2	-0.2	-0.2	-0.2	

ESTIMATED PRICE ELASTICITY OF OUTPUT

used in Czechoslovakian model

Agriculture
Food & Beverage
Metal Products & Machinery
Construction & NF Min Prod
Light Industry
Wood & Paper
Chemical
Petroleum & Refining
Other

Price Elasticity of Output				
Oil Prod.	Nat Gas	Elec.	Heat	Other
-0.11	-0.08	-0.1	-0.1	
-0.11	-0.08	-0.1	-0.1	
-0.11	-0.1	-0.22	-0.1	
-0.1	-0.4	-0.8	-0.34	
-0.1	-0.1	-0.2	-0.1	
-0.1	-0.08	-0.08	-0.12	
-0.22	-0.55	-0.3	-0.52	
-0.22	-0.55	-0.3	-0.52	
-0.1	-0.1	-0.2	-0.1	

TRANSPORTATION SECTOR ENERGY DEMAND SCENARIOS
USING THE
RMA TRANSPORTATION ENERGY DEMAND MODEL

A PORTION OF THE
ENERGY PRICE REFORM WORKSHOP
APRIL 30 - MAY 7, 1992

Presented By:

Resource Management Associates of Madison, Inc.

In Cooperation with:

Tellus Institute
and
Energy Price Reform Working Group
Government of Lithuania

U.S. EMERGENCY ENERGY PROGRAM
United States Agency for International Development
Contract No. EUR-0015-C-00-1006-00



Resource Management Associates of Madison, Inc.
Madison, Wisconsin, U.S.A.

BASELINE DATA for the TRANSPORTATION ENERGY DEMAND MODEL

A

		Estimated Social Products in mln of REAL Rubles					
		1990	1992	1994	1996	1998	2000
Gross Social Product	1	25097	20329	20329	22412	24710	27242
Indus, Agri & Constr Social Product	2	21837	17303	16207	17200	18820	20758
Agricultural	3	6335	5131	5131	5657	6237	6877
Food & Beverage	4	3580	2900	2900	3197	3525	3886
Metal Products & Machinery	5	3444	2488	2016	2016	2016	2016
Construction & NF Min Prod	6	3394	2749	2481	2481	2735	3016
Light Industry	7	2865	2321	2094	2094	2398	2901
Wood & Paper	8	691	560	560	594	630	668
Chemical	9	485	393	393	433	478	526
Petroleum & Refining	10	428	274	175	232	256	271
Other	11	615	498	498	549	606	668

		Estimated Real Annual Growth Rate (% Change)					Actual Activity (mln rbb)	
		91-92 estimated	93-94 estimated	95-96 estimated	97-98 estimated	99-2000 estimated	1989	1991
Gross Social Product	1	-0.1	0	0.05	0.05	0.05	24836	34007
Indus, Agri & Constr Social Product	2	-0.1098	-0.0322	0.0302	0.0460	0.0502	21575	5390
Agricultural	3	-0.1	0	0.05	0.05	0.05	5918	
Food & Beverage	4	-0.1	0	0.05	0.05	0.05	3752	
Metal Products & Machinery	5	-0.15	-0.1	0	0	0	3423	
Construction & NF Min Prod	6	-0.1	-0.05	0	0.05	0.05	3245	
Light Industry	7	-0.1	-0.05	0	0.07	0.1	2797	
Wood & Paper	8	-0.1	0	0.03	0.03	0.03	722	
Chemical	9	-0.1	0	0.05	0.05	0.05	522	
Petroleum & Refining	10	-0.2	-0.2	0.15	0.05	0.03	532	
Other	11	-0.1	0	0.05	0.05	0.05	644	

BASELINE DATA for the TRANSPORTATION ENERGY DEMAND MODEL

FUEL PRICES

		A							
		Real Prices 1990	Estimates of Real Energy Prices (Rubles)					Nominal Prices	
			1992	1994	1996	1998	2000	1991	1992*
Gasoline (rbls/litre)	12							0.171	3.75
Diesel (rbls/litre)	13							0.153	3
Fuel Oil (rbls/tonne)	14	24.50	317.00	456.48	456.48	456.48	456.48	83	1268
Natural Gas (rbls/m ³)	15	0.0246	0.0188	0.0270	0.0270	0.0270	0.0270	0.06416	0.075
Elec. Indust. (r/kwh)	16	0.0295	0.0750	0.1080	0.1080	0.1080	0.1080	0.02927	0.3
Elec. Transp. (r/kwh)	17	0.0230	0.0750	0.1080	0.1080	0.1080	0.1080	0.02295	0.3
Heat (r/GJ)	18	1.99	10.51	15.13	15.13	15.13	15.13	4.73	42.04
Other									

FUEL PRICE CHANGES

FUEL PRICE CHANGES		B	D E F G					
		Annual Nominal Price Changes 90-92	Annual 90-92 C&P PI	Estimates of Annual Real Price Changes				
				1990-92**	92-94	94-96	96-98	98-2000
Gasoline (rbis/litre)	12		100%	200%	20%	0%	0%	0%
Diesel (rbis/litre)	13		100%	200%	20%	0%	0%	0%
Fuel Oil (rbis/tonne)	14	619%	100%	260%	20%	0%	0%	0%
Natural Gas (rbis/m ^ 3)	15	75%	100%	-13%	20%	0%	0%	0%
Elec. Indust. (r/kwh)	16	219%	100%	59%	20%	0%	0%	0%
Elec. Transp. (r/kwh)	17	252%	100%	81%	20%	0%	0%	0%
Heat (r/GJ)	18	360%	100%	130%	20%	0%	0%	0%
Other								

* Prices for January 1992

the natural gas price is projected

** Calculation of Real Growth rates for 1990-1992:

$$r = (p92/(p90*(1+i)^2)^{0.5})-1$$

where:

r = real annual price growth rate

p92 = fuel price in 1992

p90 = fuel price 1990

i = rate of inflation (C&P PI)

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BASELINE DATA
for the TRANSPORTATION ENERGY DEMAND MODEL

ESTIMATED PRICE ELASTICITY OF DEMAND

		A	B	C	D	
		Price Elasticity of Demand				
		Oil Prod.	Nat Gas	Elec.	Heat	Other
Agriculture	28	-0.2	-0.2	-0.2	-0.2	
Food & Beverage	29	-0.3	-0.3	-0.3	-0.3	
Metal Prds & Machinery	30	-0.4	-0.4	-0.4	-0.4	
Construction & NF Min Prod	31	-0.4	-0.4	-0.4	-0.4	
Light Industry	32	-0.2	-0.2	-0.2	-0.2	
Wood & Paper	33	-0.3	-0.3	-0.3	-0.3	
Chemical	34	-0.3	-0.3	-0.3	-0.3	
Petroleum & Refining	35	-0.4	-0.4	-0.4	-0.4	
Other	36	-0.1	-0.1	-0.1	-0.1	

ESTIMATED PRICE ELASTICITY OF OUTPUT

		A	B	C	D	
		Price Elasticity of Output				
		Oil Prod.	Nat Gas	Elec.	Heat	Other
Agriculture	37	-0.2	-0.2	-0.2	-0.2	
Food & Beverage	38	-0.1	-0.1	-0.1	-0.1	
Metal Products & Machinery	39	0	0	0	0	
Construction & NF Min Prod	40	-0.2	-0.2	-0.2	-0.2	
Light Industry	41	0	0	0	0	
Wood & Paper	42	-0.2	-0.2	-0.2	-0.2	
Chemical	43	-0.5	-0.5	-0.3	-0.5	
Petroleum & Refining	44	-0.5	-0.5	-0.3	-0.5	
Other	45	0	0	0	0	

Calculations used to determine baseline data for the Transportation model

CELL CALCULATION

REF.

Passenger Vehicle Fuel Efficiencies:

- A49 Train, diesel
 $683\text{KJ/pkm} \cdot \text{GJ}/10^6 \cdot \text{L}/.037\text{GJ} \cdot 180\text{p/v} = 3.3 \text{ L/vkm}$
- A50 Train, electric
 $198\text{KJ/pkm} \cdot \text{KWH}/3600\text{KJ} \cdot 180\text{p/v} = 9.9\text{KWH/vkm}$
- B50 Trolley Bus, electric
1.916 KWH/vkm
- C49 Bus, diesel
 $14.73\text{MJ/vkm} \cdot \text{GJ}/10^6 \cdot \text{L}/.037\text{GJ} = 0.40 \text{ L/vkm}$
- D48 Van, gasoline
 $17\text{vmiles/us gal} \cdot 1.609\text{km/mile} \cdot .264\text{us gal/L} = 7.2 \text{ vkm/L or } .14 \text{ L/vkm}$
- D49 Van, diesel
 $25\text{vmiles/us gal} \cdot 1.609\text{km/mile} \cdot .264\text{us gal/L} = 10.7 \text{ vkm/L or } .094 \text{ L/vkm}$
- E,F48 Car and Taxi, gasoline
 $35\text{vmiles/cdngal} \cdot \text{cdngal}/4.2\text{L} \cdot 1.609\text{km/mile} = 13.4\text{vkm/L or } .075\text{L/vkm}$

Freight Vehicle Fuel Efficiencies:

- A57 Train, diesel
 $1.8\text{Kgce}/100\text{tkm} \cdot 621\text{t/v} \cdot \text{t}/1000\text{kg} \cdot 29.3 \times 10^6 \text{J}/\text{tce} \cdot \text{L}/.037 \times 10^6 \text{J} = 8.9 \text{ L/vkm}$
- A58 Train, electric
 $1.8\text{Kgce}/100\text{tkm} \cdot 621\text{t/v} \cdot \text{t}/1000\text{kg} \cdot 8145\text{Kwh}/\text{tce} = 76\text{kwh/vkm}$
- B57 Large Truck, diesel
 $19.2\text{goe/tkm} \cdot \text{Kg}/1000\text{g} \cdot \text{t}/1000\text{Kg} \cdot 41.9 \times 10^9 \text{J}/\text{toe} \cdot \text{L}/37 \times 10^6 \text{J} = .0217 \text{ L/tkm}$
 $.0217 \text{ L/tkm} \cdot .77[\text{capacity of utilization}] \cdot 38\text{t capacity/v} = 0.635\text{L/vkm}$
- C57 Small Truck, diesel
 $29.1\text{goe/tkm} \cdot \text{kg}/1000\text{g} \cdot \text{t}/1000\text{Kg} \cdot 41.9 \times 10^9 \text{J}/\text{toe} \cdot \text{L}/37 \times 10^6 \text{J} = .033 \text{ L/tkm}$
 $.033\text{L/tkm} \cdot .83[\text{capacity of utilization}] \cdot 19\text{t capacity/v} = 0.52\text{L/vkm}$
- D56,57 Van, gasoline and diesel
same as for a van used in passenger transportation

BASELINE DATA for the TRANSPORTATION ENERGY DEMAND MODEL

TRANSPORTATION MODEL

PASSENGER

	A	B	C	D	E	F	G
	Vehicle Types						
	Train	Trolley Bu	Bus	Van	Car	Taxi	Other
Load Factor (p/vehicle)	46	180	40	21	4	2	2
Trip Length (km)	47	112	4	9.75	13.25	13.25	13.25
Fuel Efficiency (litre/100km or KWH/100km) - base year							
Gasoline	48			14	7.5	7.5	
Diesel	49	332	40	9.4			
Electricity	50	990	192				

Passenger Trips per Day, by Vehicle and Fuel Type (thousand passenger trips / day) - base year

Gasoline	51			0	5388	45.75	
Diesel	52	84.619		1879.73	0		
Electricity	53	3.6	830.411				

FREIGHT

Load Factor

(tonnes freight/veh)

Trip Length (km)

Fuel Efficiency (litre/100km or KWH/100km) - base year

Gasoline

Diesel

Electricity

	A	B	C	D	E
	Vehicle Types				
	Train	Lg Truck	Med Truck	Van	Other
Load Factor	54	621	29.3	15.8	0.27
Trip Length (km)	55	185	83	83	83
Fuel Efficiency (litre/100km or KWH/100km) - base year					
Gasoline	56			14	
Diesel	57	890	63.5	52	9.4
Electricity	58	7600			

Ton kilometers Shipped, by Vehicle and Fuel Type (million ton km / yr) - base year

Gasoline	59			366.8	
Diesel	60	19232	5502	1467.2	
Electricity	61	28			

ESTIMATED ELASTICITIES

Gross Social Product

Elasticity of Trip Making

	A	B
62	1	

IAC Social Product

Elasticity of Shipping

63	1
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Fuel Price Elasticity of

Gasoline

Diesel

Electricity

	Trip Making	Shipping
64	-0.1	-0.1
65	-0.1	-0.1
66	-0.1	-0.1

Fuel Efficiency Elasticity of Fuel Price

Gasoline

Diesel

Electricity

	Passenger	Freight
67	-0.4	-0.4
68	-0.4	-0.4
69	-0.4	-0.4

Gasoline

Diesel

Electricity

70	10	10
71	15	15
72	30	30

**ENERGY PRICING RECONNAISSANCE TRIP REPORT
ROMANIA - RMA/ROM-PR-01**

**APPENDIX B:
DRAFT BRIEFING PAPER ON ENERGY PRICING REFORM IN ROMANIA**

Resource Management Associates of Madison, Inc.
Madison, Wisconsin, U.S.A.
April 23, 1991

Appendix B

Draft Briefing Paper on Energy Pricing Reform in Romania.

March 13, 1991

Romanian Counterpart Team
U.S.A.I.D. Energy Price Reform Project
Ministry of Resources and Industry
Bucharest, Romania.

Dear Colleagues:

Energy prices and quantities delivered have been centrally controlled in Romania for decades. This situation is now rapidly changing into a situation where energy prices will more accurately reflect both international market prices and/or actual costs. In addition, the quantities of energy consumed by various end users will no longer be centrally determined, but will be decided by the consumers themselves. A key piece of information for the consumer in deciding how much energy to purchase is the price of energy.

The prospect of paying international prices for energy may be terrifying, particularly at the adverse exchange rates now observed in the currency auctions, which recently are on the order of 200 Lei per dollar. At that exchange rate and a market based price for gasoline, the price of gasoline (without any taxes) would be on the order of 40 Lei per liter at current world oil prices. Fuel oil prices (#6) would be on the order of 29,000 Lei per ton. Electricity prices, based on Western European rates would be on the order of 8 Lei per KWH for very large industrial users and perhaps 16 Lei per KWH for small, residential users. These enormous price increases are greatly lessened by an exchange rate of, say, 60 or 100 Lei/dollar, but nevertheless, would still be quite high for Romanian users.

The purpose of the attached Briefing Paper is not, however, to speculate on the future levels of world energy prices and exchange rates, but rather, to explore the meaning of market based prices and the implications of these prices for energy users.

The Briefing Paper has been prepared by the RMA Energy Price Reform Team in Romania, part of U.S.A.I.D.'s Emergency Energy Program for Eastern Europe. We would like to use it as the basis for discussions with you regarding some of the issues raised by energy price reform in the context of Romania's move to a market economy.

The Briefing Paper includes a number of economic issues to which we have devoted much thought; but, of course, it does not reflect the same level of understanding of the Romanian economy as you yourselves already have. Please accept it as a contribution to your economic debate, and the basis for a mutual exchange of ideas in our working sessions.

Sincerely,

Mark Hanson
Team Leader

**U.S.A.I.D. EMERGENCY ENERGY PROGRAM
BRIEFING PAPER:
ENERGY PRICE REFORM IN ROMANIA**

The initial objective of energy price reform in Romania is to move energy prices closer to market-based price levels. The other principal objective is to create competitive conditions where possible. Where competitive conditions are created, it should be possible to decontrol prices. Where such conditions cannot be achieved, continued price regulation will be necessary. This briefing paper explores a number of issues related to the pricing of energy in both competitive and regulated industries. We address the following issues:

(1) **Determining Market-based Prices for Energy**

Privatization and Competition in Energy Production

(2) **Responses of Firms to Market-based Energy Prices**

(3) **Pricing Electricity: Long-run Marginal Costs vs. Actual "Accounting" Costs**

Automatic Price Adjustment Mechanisms for Electricity

Electricity Rate Design Should Reflect the Underlying Cost Structure

Other "Public Utilities" Similar to Electric Power

(4) **Energy Regulation and Private Power**

(5) **Qualifications and Limitations**

Taking Environmental Costs Into Account

The Social and Economic Effects of Rapid Price Changes

The Use of New Price-setting Procedures to Provide Financial Incentives to Competitive Enterprises

These issues are addressed in the following pages. The comments are intended to initiate a discussion with our counterparts in Romania. Out of this discussion, and the subsequent "scenario development" work which is a part of our Energy Price Reform task, we hope that useful ideas will emerge for the guidance of energy pricing policy in Romania.

(1) Determining Market-based Prices for Energy

In a country in which prices have had little relationship to market-based prices, it is no easy task to define or measure market prices or economic cost levels. Where there have been shortages, it is not clear what prices will equate supply and demand. Furthermore, some observed prices are affected by subsidies and taxes. Finally, there is a problem of circularity - the price of product A depends on the price of input product B which in turn depends on the price of input product A.

For internationally traded energy commodities, world market prices or border prices provide a yardstick. This procedure requires an actual or estimated market exchange rate between the local currency and foreign currencies. We can develop some idea of market prices in this manner.

The argument for using these prices in the situation of the move to a convertible currency and open markets is that Romanian producers of energy will have to compete with the suppliers of energy who would be willing to supply energy at these prices. In cases where Romanian providers could not compete, it would, with a convertible currency, be less costly for energy consumers and the economy to import energy.

The relationship between dollar (world market) prices for energy commodities, lei prices for energy commodities, and the lei prices of other (non-energy) goods and services in the economy is complicated. Currently, it is possible, for example, to have a large disparity between the dollar and lei prices of energy commodities, but for the relative lei prices of energy commodities and other goods and services to be quite reasonable. It is only as lei become fully convertible (i.e. as a market exchange rate becomes determined) that the use of dollar prices will be fully appropriate.

The relative lei prices of energy commodities and other goods and services has another significance in an economy with inflation. (For this purpose, inflation is defined as the average price increase in the Romanian economy. This can be measured approximately by the new index of consumer prices issued by the Romanian statistical commission.) To maintain "real" or relative energy prices constant, let alone increase them, it is necessary to increase them by as much as the general increase in prices. The statistical commission has reported that consumer prices have risen by 50% since November 1, 1990 (when the first major decontrol of prices occurred). Thus, energy prices, which have remained controlled, would have to rise by 50% to maintain the same "real" level. The use of world market prices should take this consideration into account, since, *ceteris paribus*, the dollar exchange rate of lei should fall as general prices rise.

In Romania the introduction of foreign exchange auctions has confirmed the fact that the market exchange rate is considerably lower than the pre-April 1, 1991 official rate of 35 lei/dollar, or the new exchange rate of 60 lei/dollar. More categories of purchasers of dollars will be allowed to participate in the auctions. We understand, however, that the government intends to use the new official rate, not the new currency auction rates, as the rate at which imported energy prices will be converted to lei. We propose to use the new rate as a baseline rate to use in our analysis; alternative rates

could also be considered for analytical purposes, for example 90 lei/dollar.

The principal internationally traded energy commodity is crude oil. Romanian domestic supplies peaked in 1976, and Romania now imports two thirds of its crude oil requirements. As of January 1991, oil imported from the Soviet Union has to be paid for in convertible currencies. Another major source is Iran. Imported oil can be priced at actual delivered contract prices.

Oil products such as distillate and residual fuel oil and gasoline can also be priced at delivered import prices. Natural gas too can be priced at European prices, based on deliveries from the Soviet Union or other potential sources.

Bituminous coal can be priced at delivered import prices. Romania's coal resources, which consist mostly of lignite, are not readily traded internationally owing to lignite's low energy content per unit of weight, and its high sulfur content. The use of actual Romanian accounting-based costs as a starting point may provide too low an estimate, however, as Romanian supplies are limited. The sulfur and other emissions from burning lignite in power plants also suggest that a low price would give the wrong price signal to the planners at RENEL, the Romanian electricity company. (We will discuss below the introduction of pollution costs into energy planning.)

The pricing of electricity produced from Romanian lignite is an instance in which the use of long-run marginal costs should be considered - an issue which we will take up later.

Nuclear fuel costs include the cost of uranium mining and milling, conversion, enrichment, fabrication into fuel assemblies, and certain other incidental costs such as transportation, storage and insurance. Enriched uranium, which includes the first three items, represents the greater part of the total, and can be priced at world market prices. Fabrication of the fuel assemblies, and the incidental cost items, can be added, based on actual or estimated costs for Romania's Candu reactors.

There are other fuels which are perhaps of sufficient magnitude to be taken into account, such as fuelwood. Perhaps we can be guided by actual market prices here.

Privatization and Competition in Energy Production

The Romanian government, as part of the current economic reforms, has begun to decontrol competitive industries effective November 1, 1990. The food, energy and raw materials sectors were not included; competitive enterprises in these sectors are to be decontrolled later. These reforms create the conditions in which enterprises should be able to operate with greater incentives and more flexibility.

The government is also breaking up government enterprises by restructuring them into autonomous bodies and commercial firms. As we speak, these changes are under way. In the energy sector, the supply of fuels is generally not a natural monopoly, and

from an economic point of view, decontrol should be beneficial.⁴ This would require the establishment of a number of enterprises in each "market" in order to ensure competition. A market can be defined in terms of one or more products that are close competitors within a certain geographic area.

Oil and gas exploration, development and production - provided there is equal access to pipeline networks - allow for plenty of competition. Coal markets may in many cases also allow for competition, depending on the minimum economic size of coal mining operations, coal quality differences, and transportation cost considerations.

Petroleum refining, given that there are some ten refineries in Romania and that both crude oil inputs and product outputs of refineries are internationally traded, also allows for competition.

(2) Responses of Firms to Market-based Energy Prices

To explore the effects of market-based pricing, we can develop "scenarios" or projections to test out the effects of different price levels, based on alternative assumptions about the levels of market-based prices, and how suppliers and consumers will respond to price changes. By "consumers" we mean both the residential population and industries. The two main aims of market pricing, it will be recalled, are to send appropriate prices signals to consumers on the one hand and to suppliers on the other.

The residential population accounts for a small percentage of energy use in Romania - perhaps 10%, much less than in many other countries. This makes market pricing somewhat less important for these consumers. However, their use of energy is said to be growing, and it is important that their tariffs not be set at such low levels that they have little incentive to use energy wisely. Residential consumers have extremely low gas, electricity and district heating tariffs at the present time. Bearing in mind that distribution costs are higher for small users, it would be desirable to increase prices closer to market levels. To avoid adverse social effects, a low "lifeline" rate could be maintained for a minimum KWH use corresponding to the provision of essential lighting and other requirements; for additional use, a full rate corresponding with long-run marginal cost could be applied.⁵

The most dramatic effects of market pricing of energy may come in the industrial sectors. How firms respond to the dramatically increased price levels that would result in either cost based or world market energy prices depends on a number of factors in addition to the new prices. The least response would occur if no other adjustments to market conditions were in place. In this case, each user of energy would face a higher price for energy requirements and would in turn pass on the higher cost in the form of

⁴We understand that the government is taking into account other factors such as national security in its determination of ownership options for energy supplies.

⁵Gasoline prices are currently set in this manner. It is easier to apply a two-step tariff to electricity.

higher prices for products.

If however, incentives were put into place whereby energy savings which would reduce energy costs and some type of reward were to occur to managers and/or workers who brought about the energy savings, then energy and product costs would increase less than in the case of no adjustments. Depending how easily energy reductions could be put into place, overall energy costs might even decline as a result of the incentive system. Establishing fair, efficient, and effective rewards is a complex task. To avoid all of the complications involved in establishing a reward system, a free market system could theoretically be adopted which would leave decisions on rewards up to the owners of the plants (which might include the workers) and their managers.

Within a free market system where not only energy prices, but all commodities, services, and even labor, are provided at market prices, the firm (in theory) will purchase all inputs, including energy only to the degree necessary. Furthermore, the firm will actively pursue conservation or energy efficiency measures to the point where the last Lei invested in conservation in the factory will result in the same return as the last Lei spent on other investments or other inputs, such as energy. The incentive for this behavior which minimizes all costs is that it will maximize profits for plant owners. In cases where market imperfections exist, this implies the opportunity to maximize excess profits. Under perfectly competitive conditions, this implies that the firm will be able to survive, pay workers and managers, and provide sufficient profits to plant owners (workers, managers, outsiders etc.), to justify their investment in this particular plant. The greatest response to energy price increases will occur under these conditions.

In practical terms, what this means for a given firm may vary considerably from firm to firm. To provide a comprehensive review of the potential responses is probably impossible. However, it is instructive to consider two hypothetical situations, one in the power industry and the other an industrial plant.

District Heating Plant

District heating plants in Romania are common and typically produce power, steam, and hot water for residential and sometimes industrial users. In at least some of these plants, there is difficulty in meeting all customer needs due to problems of fuel availability and maintenance, which may be aggravated by the fuel quality that has been available.

With a shift to world energy prices, energy input costs of plant operation would increase dramatically. If revenues to the plant are sufficient, however, the plant would be able to obtain sufficient energy supplies. The high cost of energy would evoke both short term and long term responses. In the short run, any cost effective measures to reduce energy losses would be undertaken. For example, this might involve the repair of pre-heaters, increased insulation of steam and hot water lines, increased maintenance of steam lines, boiler tuning, etc. In the long run, depending on the age of the boilers, and their need for overhaul, it is possible that fuel substitution would become appropriate. While this would be quite capital intensive, the cost differential between fuel oil or

natural gas and coal is so large that it may be justified to install a coal boiler (with pollution controls) to reduce overall plant costs.

Alternatively, depending on the solid waste situation, it may be cost effective to utilize fluidized bed technology and burn municipal waste, as is common in Switzerland and Germany.

Industrial Plant - Paper Mill

The responses in a paper mill to changes in energy prices would be somewhat similar to those for the district heating plant. Because the energy cost component of the paper mills is a much lower percentage than that for the district heating plant, the types of measures undertaken to reduce energy costs may be somewhat different.

In the short run there would be various maintenance issues to bring the mill up to top efficiency. In the longer term, process changes and other capital-intensive modifications would likely be justified. For example, it could be appropriate to introduce a much higher level of heat recovery (using heat exchangers) from the numerous waste flows at the mill. Depending on the cost of the wood raw material, the types of wood waste (if any), and the type of paper being produced, it could be cost effective to install a new boiler which would have dual fuel capability to burn wood and/or natural gas.

What is evident from these two hypothetical cases is that the introduction of world energy prices could result in considerable changes. These changes range from lower cost measures, which could be implemented fairly quickly, to longer term measures which might significantly alter the fuel balance in Romania away from oil and gas which on the world market are expensive fuels. These changes would be the result of the change in prices, the introduction of some new technologies as the Romanian economy is opened up to technologies available on the global market, and the impacts of incentives to make these changes due to the need to compete (and profit) in the market place.

It is also possible that some plants can not survive in the market place because energy costs will be too high. These will be industries where energy use is very high and where Romanian firms will have to compete with firms in other countries that do not have to face world market prices for energy (or other inputs). Aluminum production is one example. This industry is dominated by firms that have captive hydropower or hydropower from state owned utilities. The importance of power cost to this industry is highlighted by the fact that plants are moving from some regions with considerable hydropower and attractive power rates (e.g. the Northwestern U.S.) to other regions (Amazon Basin in South America) and locations in Africa, where hydropower rates are even lower.

(3) Pricing Electricity: Long-run Marginal Costs vs. Actual "Accounting" Costs

Certain energy suppliers, including all or part of the electricity industry, are likely to remain natural or de facto monopolies⁶ in Romania. For such firms, the major problem with using world market prices or equivalent current lei prices for energy pricing and planning purposes relates to divergences between current or "accounting" costs and long-run marginal costs. The issue is highly important because pricing should in general reflect not only current costs but future costs, such as new investment costs, that may be incurred. As noted above, this problem arises with respect to non-traded items such as lignite, as well as electricity, as will be discussed below, even though electricity is traded internationally.

The classic example of the need to use long-run marginal costs relates to pricing the use of a bridge for automobile traffic. Once the bridge has been built, its cost is "sunk cost" and from a strict economic point of view, its use should be free, since the short-run marginal cost is zero. (Of course, as a practical matter a toll may need to be charged to recover the cost to the public authority of financing the construction.) But consider the price "signal" that the users are getting, if the price is set at zero. With no charge, consumers will tend to increase their usage, and eventually may approach the maximum capacity of the bridge, resulting in the economic cost of congestion delays or, ultimately, the cost of a new bridge.

In anticipation of this situation, a "full" price can reasonably be set to include the cost of a new bridge, which is the long-run marginal cost. By charging users this full price, they would be getting the right price "signal" regarding the costs incurred by their usage.

Now consider a very similar example in the energy market. Existing hydro-electric facilities cost very little to operate - most of their cost is "sunk" cost. But if their output is charged at a very low rate, it will encourage consumers to increase their usage, which in turn will require the construction of expensive new electric energy facilities.

One solution to this problem lies in the use of long run marginal costs for electricity pricing in particular. The calculation of long run marginal costs can be complicated, and there have been many methods used to estimate them for the United States electrical generating system, for example. One method is to measure such costs from the full costs (investment costs as well as fuel and other operating costs) of the most economical new source of electrical energy.

For Romania, there are at least two candidate sources of "new" electricity supply, after certain coal-fired and hydroelectric plants currently under construction have been completed. Probably the most economical one is the increased output and capacity which could be obtained from better maintenance and repair of existing coal-fired

⁶A de facto monopoly would exist in an industry with less than three firms, even though the industry is not a natural monopoly.

generating units. This might provide a low estimate of marginal cost. Whether it is a good estimate would depend on the period for which this source is sufficient to provide for Romania's electricity requirements. We don't know the answer to that question at this time.

If we assume that additional electric generating capacity will be required in the foreseeable future to meet Romania's electricity requirements, the next source of electricity in practice is likely to be the first Candu nuclear reactor.

Five 750MW nuclear units are under construction or planned at Cernavoda in south-eastern Romania near the Black Sea. We do not know the exact status of these units; we understand, however, that the reactor has been installed in Unit One and General Electric turbines have been installed in Units One to Three. We also understand that Unit One is scheduled for service in 1994. An additional site has also been tentatively identified for further nuclear units.

In order to calculate the cost of nuclear power, the construction cost of Cernavoda Unit One will need to be estimated, and converted into a per-KWH "fixed charge" based on reasonable assumptions about finance costs, capacity factor, and life of the unit. Addition per-KWH costs include nuclear fuel costs, and other operating and maintenance costs. Nuclear fuel cost should be relatively low, but construction costs will be high.

There are, then, at least two new sources of electricity which could be used to estimate marginal electricity costs in Romania. The first is electricity from the additional capacity which would be created by repairing and maintaining existing generating units which are out of service or operating below full availability or reliability levels. The costs of this source include the costs of new investments to get the plants running properly, and the ongoing fuel costs (coal) and other operating and maintenance costs.

The other source is nuclear power from the first Candu unit, including the fixed cost of investment in the plant and the investment in transmission facilities to bring the power to market, and ongoing nuclear fuel and other operating and maintenance cost. In the case of a nuclear unit, it is also necessary to take into account "capital additions" (additional capital investments during the life of the plant) and to make provisions for disposing of the radioactive nuclear waste and decommissioning the reactor at the end of its useful life.

Electricity is an internationally traded commodity in Eastern Europe. From a short-run marginal cost standpoint, it is economical to operate the existing electricity system in Romania in such a manner as to minimize short-run fuel and other variable operating and maintenance costs, and to purchase imported electricity if the cost is less than the domestic short-run marginal cost. (Likewise, it is economical to export electricity if the reverse situation is true.) However, the long period required to plan additional new generating units necessitates the use of long-run marginal costs in

planning new units, in contrast to minimizing the operating costs of existing units.⁷

There are, however, a number of considerations which suggest that world prices might not always be appropriate prices to use in Romania. The costs of producing electricity (and possibly certain other energy commodities) in Romania may be less than in other countries, in part due to lower wage rates and higher efficiencies in some energy conversions. If this is the case and if there are some barriers to imports and exports for lack of adequate transmission lines etc., an argument can be made that certain energy prices should be set to cover only actual "accounting" costs.

Prices that cover actual costs should, by definition, provide sufficient revenues to cover the expenses of the industry. This level of costs should not require any subsidies because, in a free market economy at equilibrium, energy prices include a normal profit (sufficient profit to provide a necessary return on capital to justify the capital investment on the part of investors).

Thus, cost based prices would provide for normal profits while world prices would actually provide excess profits. This raises important policy questions. With prices based on actual costs, do consumers have sufficient incentive to conserve energy resources economically? Also, would sufficient incentive exist for the firm to make new investments, if prices are based on actual costs? If world prices are used (and the excess profits can be retained by the firm), an incentive would exist to increase production either through expansion of existing firms or through the addition of new firms to the market. If the country imported energy, such expansion would serve to reduce the level of energy imports while if the country were an energy exporter, the increase in energy production would permit further increase in exports.

There will be some complicating factors in this analysis. For example, the production of district heating (hot water for building heating) and steam for industrial process use raises the issue of allocating costs between the electric and thermal output.⁸

⁷The overall economic objective for regulated or mixed industries is usually stated as "least cost integrated planning" (LCIP). This requires that a reliable level of service should be provided at the lowest reasonable cost to society. Cost should include environmental effects of the service, as discussed below. "Integrated" means that investments in energy conservation should be made up to the point at which the marginal cost of a KWH saved is equal to the marginal cost of a KWH produced.

⁸One solution to this cost allocation problem is to allocate to electricity production those capital costs (construction costs multiplied by a fixed charge factor representing financial costs, amortization, etc.) and fuel and other operating and maintenance costs which would be incurred if the plant were designed and operated for electricity production only. The additional capital costs and fuel and other operating and maintenance costs incurred to run the plant as a cogeneration facility would then be allocated to the thermal output.

Automatic Price Adjustment Mechanisms for Electricity

Energy price reform in Romania is taking place within the context of general price decontrol. It is important for energy prices to be able to adjust for general inflation in the economy, and to increase by a larger amount than general inflation in order to move towards market prices.

This problem is particularly serious for the electricity sector, which has tariffs that are difficult to change quickly, but which depends on fuel purchases which can have rapid price increases.

An automatic fuel adjustment clause provides a mechanism for quickly passing increases in fuel costs through to consumers.

Electricity Rate Design Should Reflect the Underlying Cost Structure

This paper will not develop the issues in rate design which are obviously important in making the prices of electric service reflect the underlying costs. Suffice it to say here that rate design typically takes into account actual accounting costs. The use of long-run marginal cost based rates should be encouraged; at a minimum, rate design can be influenced by marginal cost considerations as well as accounting costs.

Secondly, tariff design can take into account voltage level of service, load factor, time of use, and different reliability levels, etc., all of which affect costs.

Other "Public Utilities" Similar to Electric Power

The reason for treating the transmission and local distribution - and possibly the generation - of electricity differently from the energy fuels is the existence of a natural monopoly.

Certain other energy industries are also characterized as natural monopolies. In particular, the pipeline systems for natural gas and oil are unlikely to be sufficiently competitive to allow for competition. And the railway network for coal transportation is the same.

(4) Energy Regulation and Private Power

Where there is insufficient competition in a market, for example when there are fewer than three firms in the market, some means must be found to regulate prices in the public interest, to avoid unjustified increases of prices.

The traditional means of regulation of such "natural monopolies" as electric utility companies in the United States, for example, is based on allowing the firms to set prices equal to their current costs plus a cost of capital invested. The capital cost is equal to the sum of (1) depreciation expense of the capital equipment and (2) the cost rate or "interest rate" for capital multiplied by the amount of the investment. The annual

depreciation expense is usually simply the initial cost of the plant and equipment divided by the expected useful economic life of the plant and equipment; depreciation on each item or group of items is calculated separately based on the particular depreciation rate. The amount of the investment in each year is equal to the original investment cost less accumulated depreciation to date; this is called "net book value."

This procedure provides a reasonable starting point for discussion of regulatory pricing. Critics of the procedure say that it gives the firm no incentive to reduce costs because they can always be passed along, and it is true that many inefficiencies are allowed. However, government regulators can "audit" the books of the firm to ensure that there is no fraud, and they also require the firm to show that its plans and operations are reasonably efficient.

The outcome is a system that can work reasonably well, although there have also been significant problems. Perhaps the most salient problem in the United States has been that the firms built too much generating capacity (particularly nuclear power plants), being less careful than a firm in a non-regulated market would have been to make sure that the capacity was needed and that it was not too expensive.

There are several different models for non-competitive markets. In the United States there have been several models. First, there are the large number of regulated, privately-owned companies that provide most of the electricity in the country. They are regulated in the manner outlined above, mostly by regulatory commissions which have been established in almost all of the 50 states. The owners attempt to increase profits, while the commissions resist rate increases above the levels necessary to earn their "interest rate" which is called the "cost of capital" or a "fair rate of return" on the capital invested.

The companies earn sufficient profits to cover their investments, but are not allowed to earn excess profits. It is sometimes necessary for commissions to provide additional incentives for desired investments, or to order the companies to make them. The commissions also review the operating efficiency of the companies, and their investment plans, to see that they are keeping costs as low as reasonably possible. However, the commissions do not attempt to manage the companies. It is the managers' job to manage, and the commission will only review the management decisions. In practice, the commissions are hampered by the difficulty of fully scrutinizing the practices of the companies.

A second common model is the "public power" model which has two types. There are "rural electric cooperatives" which are owned by their members (farmers and others); and there are "municipal utilities" which are sometimes part of a town government or may be separate authorities. The largest of these is the Los Angeles Department of Water and Power. In each case, these public power systems are under democratic control by their members or the voters in their districts. The dispersion of ultimate authority across the whole local population has weakened the democratic controls that, in theory, are very strong.

The new model which is being fostered in the United States today is the "independent power" or "private power" company. Small and medium-sized power plants are being built by independent companies, and the large regulated companies are being forced by the commissions to buy power at rates equal to the marginal cost of generating power on the large company's own system. In this manner, it is hoped that competition will be created and the generation of power can be deregulated.

This raises an important point about the structure of the electricity industry. It consists of three levels - generation, transmission and local distribution. There is a movement in such countries as the United Kingdom and the United States towards decontrol of prices, as generation becomes sufficiently competitive. However, transmission and local distribution are "natural monopolies" (it is uneconomical to have more than one firm providing the service in a particular area.) These levels will require continuing regulation. It is therefore only the generation of electricity that will likely be decontrolled.

(5) Qualifications and Limitations

Taking Environmental Costs Into Account

For some fuels such as lignite and high sulfur fuel oil, the environmental effects are so significant that even in the initial stages of price reform it may be worth taking them into account. (Indeed, the burning of all fuels affects the environment, and the true economic costs of such effects should be taken into account in the long term.)

For purposes of this analysis, we can assign physical pollution coefficients to electric energy generation from each specific fuel. The amounts of SO₂ emitted can be estimated, for example. Monetary costs can also be estimated, based on the costs of remediation or the estimated health and other costs of the emissions. At this stage, any estimates developed will obviously be very preliminary. Nevertheless, if environmental costs are included in the costs of electricity generation from alternative fuels such as coal, oil and gas, the choice of fuels could be affected. If pollution damage and/or control costs are included, the cost of electricity will be increased.

The Social and Economic Effects of Rapid Price Changes

There are obviously serious concerns regarding the speed or completeness with which energy prices should be adjusted. It is a major political decision how quickly and even how fully prices should be changed to correspond with market-based prices.

From an economic standpoint, the more quickly consumers receive a clear price signal about the costs of their usage, the more quickly they will have the opportunity to respond in an economical fashion. For purposes of this analysis, we assume that there are overall economic advantages to such adjustments. The objective of sending the appropriate price signal to consumers is give each consumer an incentive to set his or her consumption at the level at which he or she is willing to pay the true cost of energy to society.

For industrial consumers of energy, there is the choice of which products to produce, how much to produce, and what techniques to use in production. In energy-intensive industries, these decisions will be influenced by the prices that have to be paid for energy inputs. It must be expected that if energy prices are increased significantly, the production of some products may be affected. Among these are the aluminum and steel industries, for example. Certain products may no longer be economical in the same amount, or perhaps at all, which could have major impacts on the overall economy. New techniques may be necessary which use less energy.

The Use of New Price-setting Procedures to Provide Financial Incentives to Competitive Enterprises

Finally, we need to revisit the reasons for price reform and the way in which prices are set. So far, we have emphasized the need for prices to reflect input costs, and have considered the use of pricing based on long-run marginal costs. Prices so determined will send out the correct price signals to purchases of the product.

But what about incentives for the suppliers themselves? We have not fully considered the more complex pricing issue regarding deviations of market prices from input costs in order to increase a firm's "profit." We use the term "profit" here simply to mean the difference between sales revenues and the costs of materials, labor and all other inputs, including the interest cost on borrowed capital. What remains is the firm's profit or net income.⁹

We have assumed that the first priority in Romania is to set prices closer to true cost levels. The second, or a parallel, step can be to allow enterprises to increase their profits by, for example, reducing their costs by greater productivity, and retaining the profits that result. This would be appropriate, we believe, in competitive sectors. (Competitive industries have been defined in the new Romanian market economy legislation as those in which there are three or more firms.)

A "normal" rate of return on capital is the rate of return which is comparable to that earned in other investments involving the same level of risk. The investor is always trying to increase his or her level of return above the normal rate; and of course is trying to make sure that the return does not fall below the normal rate. The importance of allowing profit levels to vary according to each firm's success in reducing costs (and/or of course finding new markets) is to create a very strong incentive to the owner/managers to ceaselessly attempt to improve productivity and to seek out new markets in which the firm can earn greater profits. The lack of such incentives in the Romanian economy is a major obstacle which the reforms are aimed at addressing. Such incentives will ensure that the Romanian economy will respond more rapidly to the economic challenges it is facing.

Resource Management Associates/ Tellus Institute
Bucharest, Romania, March 12, 1991

⁹If there are taxes on profits, net income after tax is equal to net income before tax minus taxes; this paper does not go into tax issues.

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Chapter 3

Energy Use and Economic Variables

by Richard S. Mack and H. F. McDuffie

I. Introduction

Because increases in energy use have historically accompanied economic growth, it is tempting to think of the two variables as directly correlated. However, attempts to specify and quantify their relationships have led to discrepancies of magnitude and often of direction. It seems clear that economic activity not only affects energy use, but the availability of energy and the ways in which it is used affect a number of economic variables.

This chapter examines several aspects of the energy/economy relationship. Section I is an overview of changes in historical patterns of energy use. Section II considers the quantification of the relationship between gross national product (GNP) and energy inputs. Section III views the explicit microeconomic relationship between energy price and quantity used in the industrial sector.

II. Historical Perspective

The history of industrial civilization has been the history of man's ability to acquire, use, and control sources of energy and power beyond those derived from human and animal muscle or the limited use of water power for mechanical energy. Energy use increased from a per capita consumption of 2,000 kilocalories per day associated with basic food consumption in a hunting and gathering society to 12,000 kilocalories per day under primitive agriculture. During the period of the low-technology industrial revolution (1850–1870), usage reached 70,000 kilocalories per

day; in the United States current per capita usage is 276,160 kilocalories per day.¹

The acceleration in energy use is usually associated with the development of steam as a prime mover in the industrial sector. The associated development of steel technology and rail transport is directly linked to the mobility of steam power relative to the stationary nature of water power.² Just as the use of coal extended the industrial horizon and stopped the destruction of the forests of Western Europe and North America, the later discovery of technologies for recovering and using petroleum and natural gas led to further industrial advances including the internal combustion engine and the steam and gas turbine. Each of these developments reinforced the pattern of accelerating use of energy, which was coupled with increases in the demands for industrial output.

The U.S. has been extravagantly blessed with plentiful and easily available resources. With only limited restrictions on exploitation, the U.S. has been using these resources, especially petroleum, at a high and accelerating rate. Figure 3.1 shows the historical trends in fuel consumption. A cogent historical perspective is given by M. King Hubbert, in his comments on fossil fuels:

If these substances [fossil fuels] continue to be used principally for their energy contents, and if they continue to supply the bulk of the world's energy requirements, the time required to exhaust the middle 80% of the ultimate resources of the

1. Earl Cook, "The Flow of Energy in an Industrial Society," *Scientific American* 224, no. 3 (September 1971).

2. Chauncey Starr, "Energy and Power," *Scientific American* 224, no. 3 (September 1971)

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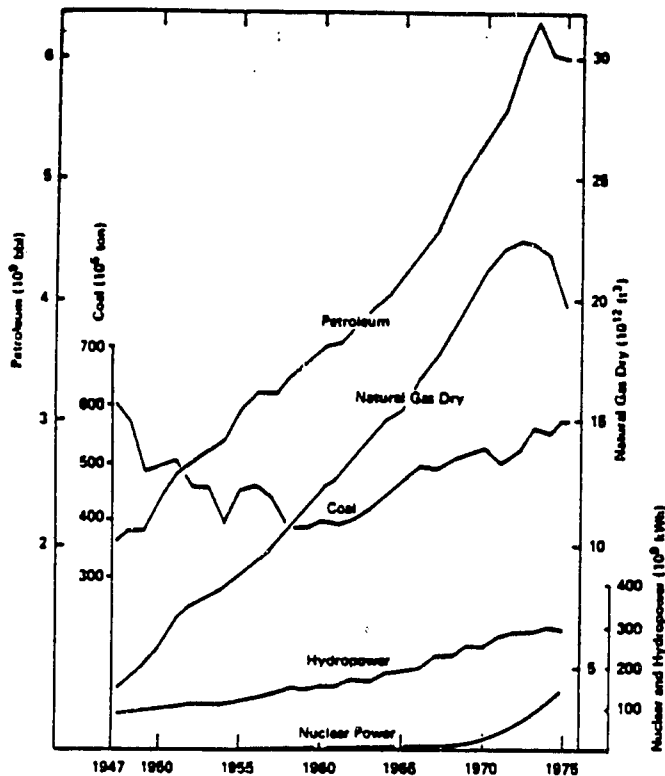


Figure 3.1. U.S. gross consumption of mineral energy resources and electricity from hydropower and nuclear power in physical units, 1947-1975. Levels for 1975 are projected.

Source: U.S. Energy Research and Development Administration. *Administrator's Energy Data Book* (July 1976), p. 201.

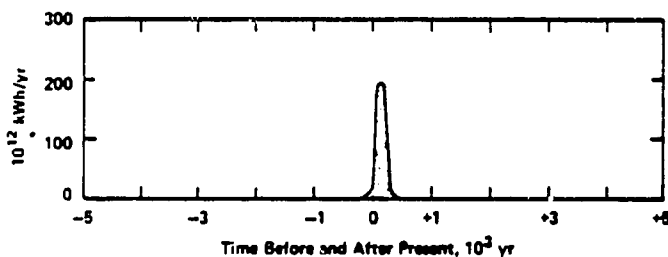


Figure 3.2. Complete cycle of world consumption of fossil fuels on a time scale of 5,000 years before and after the present

Source: Reprinted with permission from M. King Hubbert, "Man's Conquest of Energy: Its Ecological and Human Consequences" in *The Environmental and Ecological Forum, 1970-1971* (Washington, D.C.: U.S. Atomic Energy Commission, Office of Information Services, 1972), p. 27.

members of the petroleum family—crude oil, natural gas and natural gas liquids, tar-sand oil, and shale oil—will probably be only about a century.

Under similar conditions, the time required to exhaust the middle 80% of the world's coal resources would be about 300 to 400 years (but only 100 to 200 years if coal is used as the main energy source).

To appreciate the bearing of these conclusions on the long-range outlook for human institutions, the historical epoch of the exploitation of the world's supply of fossil fuels is shown graphically in [Figure 3.2], where the rate of production of the fossil fuels as a function of time is plotted on a time scale extending from 5,000 years ago to 5,000 years in the future—a period well within the prospective span of human history. On such a time scale, it is seen that the epoch of the fossil fuels can only be a transitory and ephemeral event—an event, nonetheless, which has exercised the most drastic influence experienced by the human species during its entire biological history.³

Thus, in the long run, or even in the moderately short run of only a few generations, we are following a course that is most certain to exhaust our resources of easily available fossil fuels. This consumption is aggravated by the world population explosion and the rising expectations of members of the Third World. Solar and other forms of renewable energy, including biomass not requiring synthetic fertilizer, can certainly contribute in substituting for fossil fuels. Other conservation measures likewise can reduce our consumption and raise the ratio of gross domestic product (GDP) to energy used.⁴

The expansion of the world's economy has been largely based on a long decline in the price of energy. Figure 3.3 shows the recent history of the real price of industrial energy and the very abrupt rise beginning in 1973 with the increase in the price of oil from the Organization of Petroleum Exporting Countries (OPEC) accompanied by increases in the prices of coal and natural gas.

3. M. King Hubbert, "Energy Resources," Chapter 8 of *Resources and Man* (San Francisco: W. H. Freeman and Co. for National Academy of Sciences, National Research Council, 1969), p. 205.

4. GDP equals gross national product (GNP) less net property income from abroad.

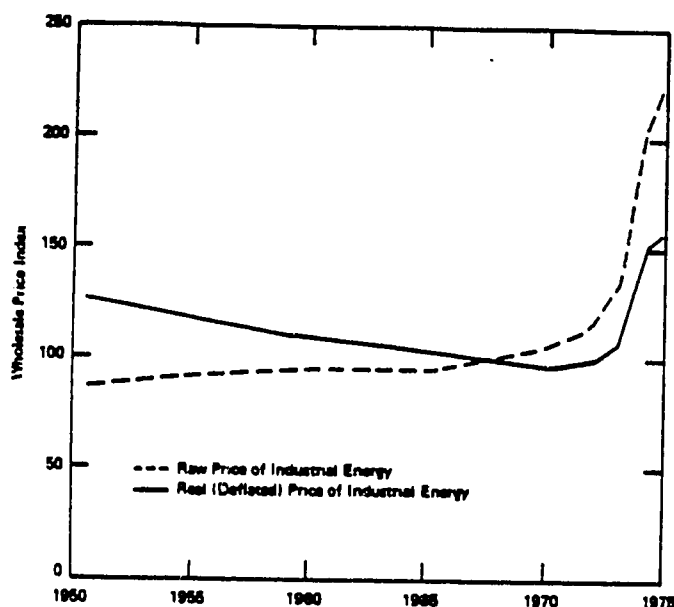


Figure 3.3. History of real energy price

Source: R. W. Barnes; printed in National Research Council, *Alternative Energy Demand Futures to 2010*. The Report of the Demand and Conservation Panel to the Committee on Nuclear and Alternative Energy Systems (CONAES) (Washington, D.C.: National Academy of Sciences, 1979), Figure 22, p. 98.

III. Relationship of Energy to Economic Output

Because energy is a factor of production, it relates both as a substitute and a complement to other factors of production, depending upon the length of time of the analysis. Because of the high levels of unemployment experienced over the past decades, the relationship between labor and energy intensity is of particular concern. Figure 3.4 portrays the relationship between energy intensity and labor intensity for a number of industrial products. Note that energy and labor usages are in part determined by the product mix within the economy. The energy and labor quantities of Figure 3.4 are based upon the total requirements (direct and indirect) to effect marginal changes in final demand.

With respect to the variables of energy use and sectoral economic growth, Figure 3.5 shows the effect of 10% growth of each industry upon energy use and employment in the entire economy. Note that first quadrant industries show a complementary relationship and are primarily agricultural. Growth in industries in the second quadrant is accompanied by expansion of total energy use and contraction of employment in the entire economy; these second

quadrant industries primarily produce basic materials. Third quadrant industries show simultaneously negative changes in both labor and energy use, reflecting the use of technologies that are labor saving, but not energy intensive, as inputs to increased production. This situation contrasts with quadrant four, where low wages reduce the need for labor-saving technology. It is noteworthy that over half of the industries fall into quadrant two, indicating the substitution effect associated with sectoral growth.⁵

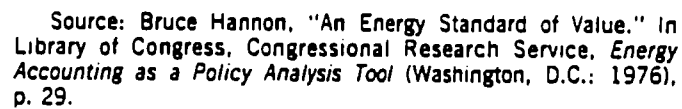
As for the relationship of energy and total output, Figure 3.6 shows the relatively steady increases in both variables. The late downturn in both energy consumption and GNP is a function of the 1973 oil embargo and the reduced levels of economic activity during the 1974–1975 recession.

The expanded scale in the lower part of Figure 3.6 shows the ratio of energy use to GNP, expressed in watt-years per dollar (Wyr/\$). All the changes shown fall within a range of $\pm 5\%$ and, thus, may not be significant. Nevertheless, the decrease in the ratio until 1966 is a continuation of a general trend which began in 1920. Reduction of the ratio of energy to GNP during this period is explained by increases in the efficiency of energy conversion and by growth by the service sector, which is a less energy-intensive contributor to GNP. Since 1967, the increase in the ratio may be due to the substitution of electricity for many direct fuel uses, as well as the rapid growth of air conditioning as a primary electrical use that has little multiplier effect on GNP.⁶ The 1970–1972 peak is associated with the flat portion of the GNP curve above. Since the oil embargo, higher energy costs and resultant decreases in efficiency (from general business slowdown and from use of sources that are less energy efficient) may be causing an upturn in the ratio; continued increases in energy cost should eventually force a less energy-intensive industry mix.

The relationship between energy consumption per capita and the gross domestic product of nations is shown in Figure 3.7. Naturally, there is some variation among nations with regard to this relationship, because nations have differing amounts of various resources, investment capital, and labor, and different cultures and life-styles.

5. Bruce Hannon, "An Energy Standard of Value," *The Annals of the American Academy of Political and Social Science*, no. 410 (1973), pp. 139–52.

6. Cook, "The Flow of Energy in an Industrial Society."



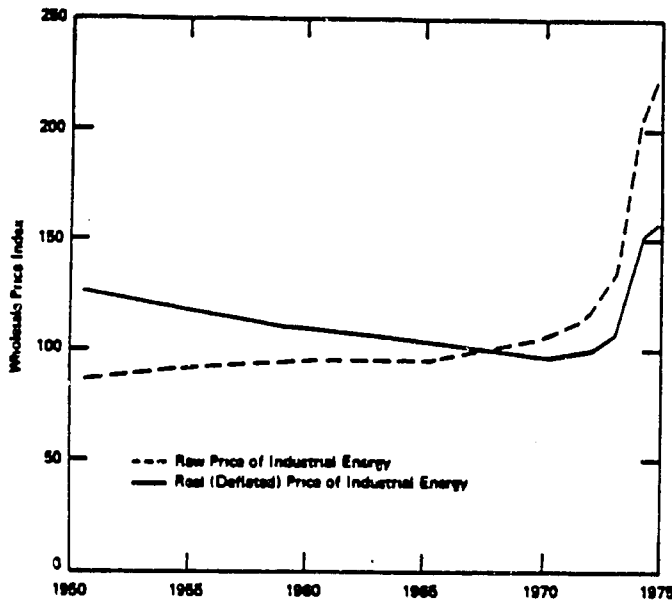


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6. Cook, "The Flow of Energy in an Industrial Society."

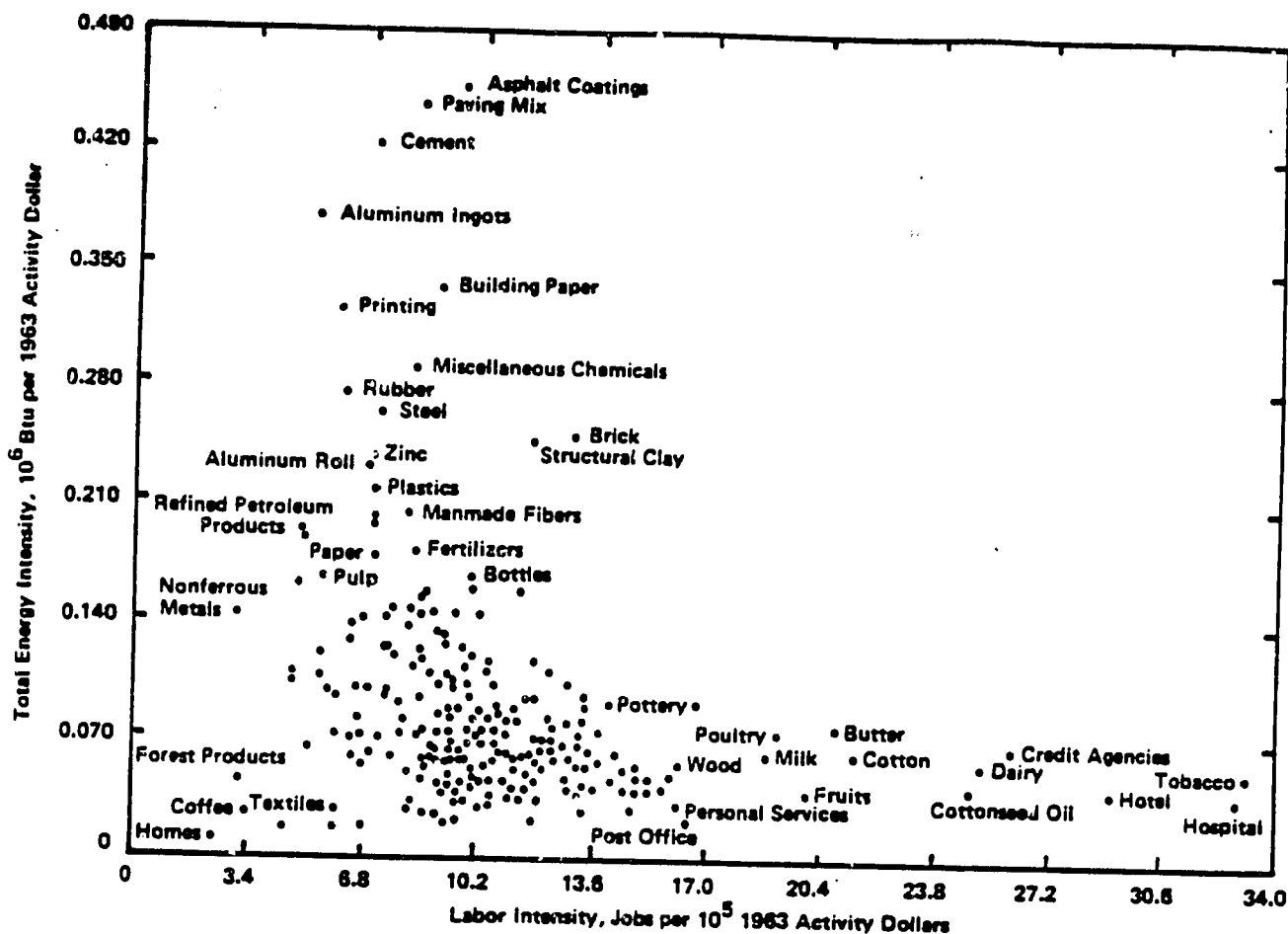


Figure 3.4. Total (direct and indirect) energy and employment intensities for all U.S. industrial sectors, 1963

Source: Bruce Hannon, "An Energy Standard of Value." In Library of Congress, Congressional Research Service, *Energy Accounting as a Policy Analysis Tool* (Washington, D.C.: 1976), p. 29.

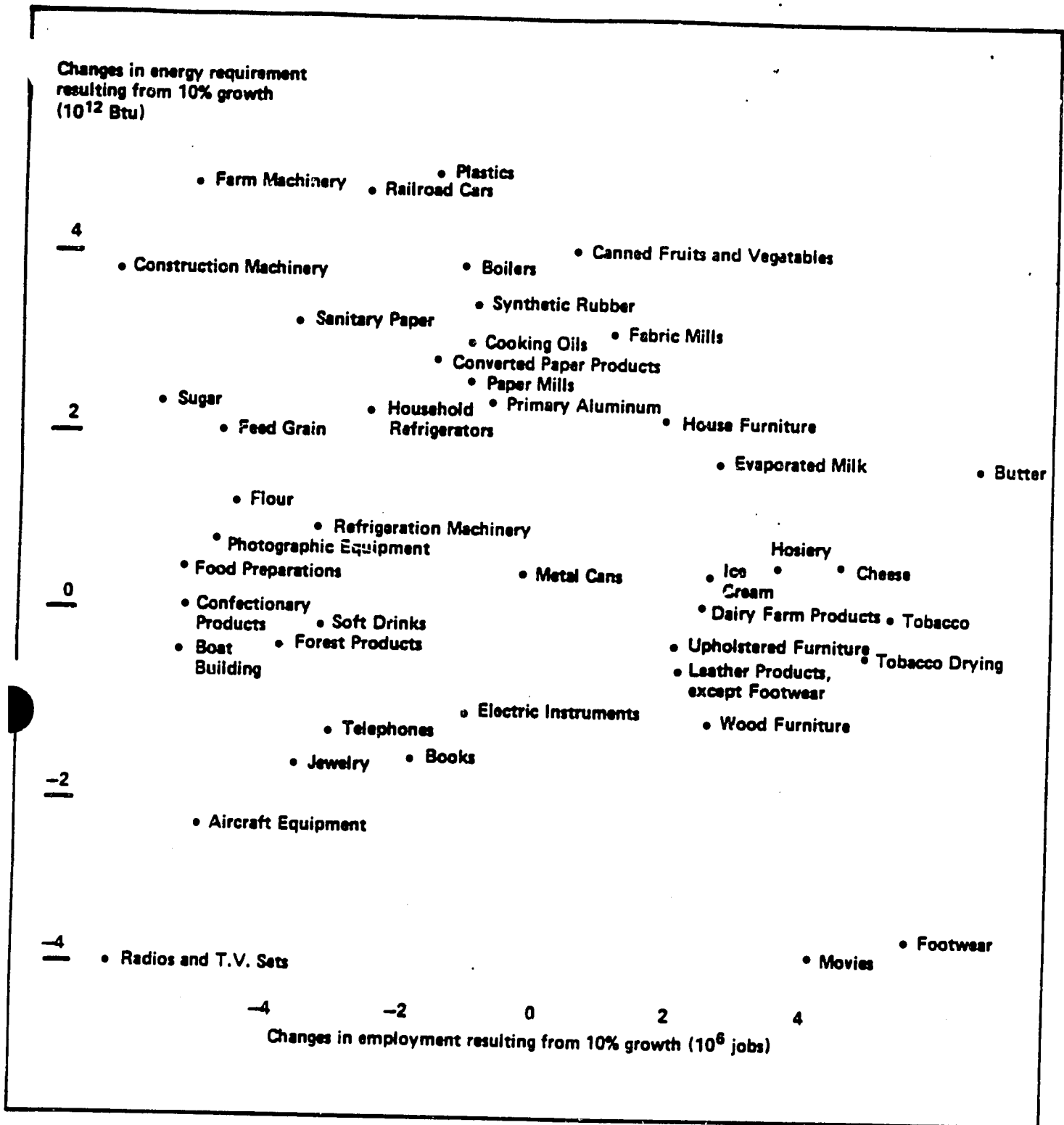


Figure 3.5. Employment-energy trade-offs: effects of differential growth in specific industries

Source: Reprinted with permission from Bruce Hannon, "Options for Energy Conservation," *Technology Review* (February 1974): 26.

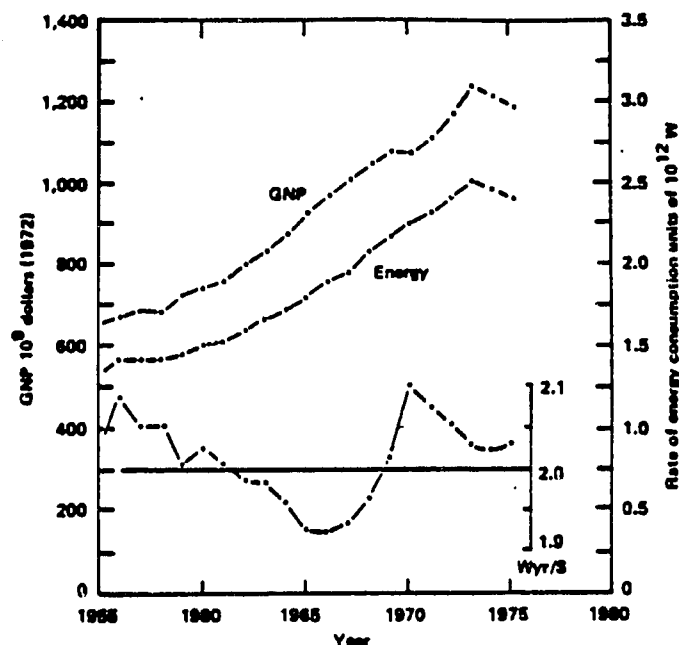


Figure 3.6. The correlation between energy consumption and economic activity, 1955-1975

Source: Reprinted with permission from Jerrold H. Krenz, "Energy and the Economy: An Interrelated Perspective," *Energy* 2, no. 2 (June 1977): 116. ©1977 Pergamon Press Ltd.

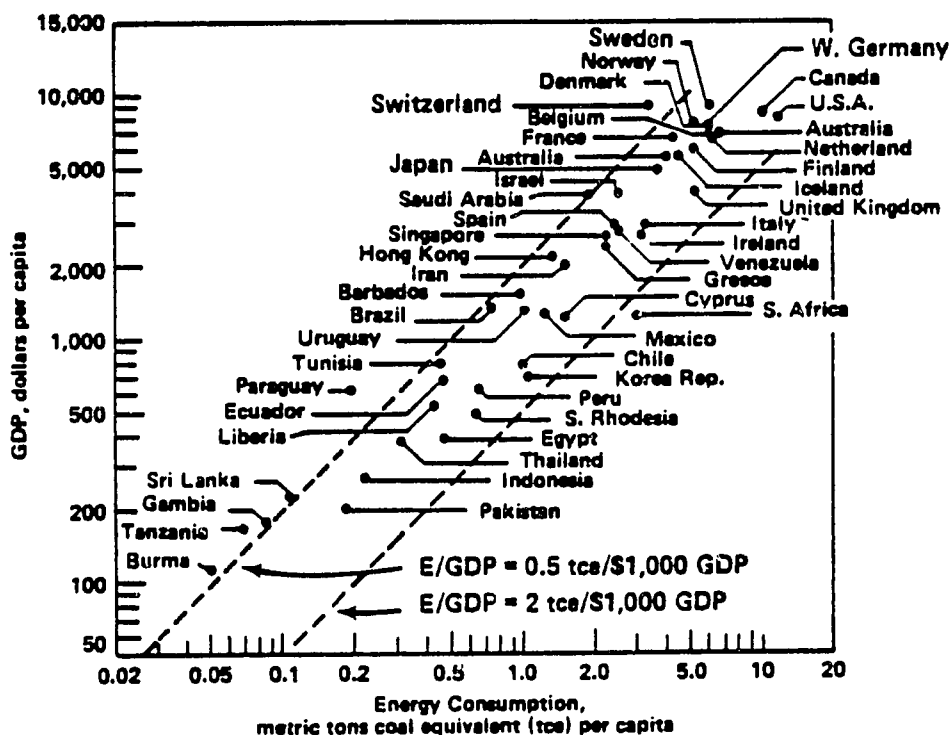


Figure 3.7. Relationship between gross domestic product and energy consumption per capita for 48 countries, 1976

Source: U.N. data; printed in Henry R. Linden, Joseph D. Parent, and J. Glenn Seay, *Perspectives on U.S. and World Energy Problems* (Chicago: Institute of Gas Technology, February 1979), frame 5.

IV. Responsiveness of Industrial Energy Use to Variations in Energy Prices and Sectoral Output

Price elasticity of demand is an analytic measure of the responsiveness of quantity demanded to changes in price. More specifically, the coefficient of price elasticity represents the percentage response in quantity demanded which results from a given percentage change in price. Simple or "own" price elasticities are always negative, indicating an inverse relationship in that an increase in price will decrease the quantity demanded.

Demand is deemed "elastic" if a given percentage change in price results in a larger percentage change in quantity demanded. This situation represents a high degree of responsiveness to price change. Elastic conditions are indicated by a coefficient of elasticity which falls between -1 and $-\infty$. On the other hand, if a given percentage change in price results in a smaller percentage change in quantity demanded, then the relationship is termed "inelastic"; inelasticity is denoted by a coefficient which ranges between 0 and -1 . In the industrial sector, relative inelasticity in the demand for energy, particularly in the short run,

results from the technical inability to substitute other fuels in response to price increases. In the long run, when changes in capital equipment are possible, responsiveness tends to be more elastic. As for special cases, a coefficient of 0 indicates no response to a change in price, whereas a coefficient of -1 indicates a situation of percentage changes in quantity that are equal to the initiating changes in prices.

Price elasticities for energy demand in the industrial sector are presented in Tables 3.1 through 3.5. Table 3.1 treats energy in the aggregate, whereas Tables 3.2 through 3.5 treat electricity, coal, natural gas, and petroleum. Although there are great variations in magnitude, there are no zero elasticities; this fact attests to the concept that quantity demanded responds to changes in price. Similarly, the tables show energy demand to be more inelastic in the short run, reflecting the inability to substitute other fuels without time-consuming capital investment.

Right-hand columns of Table 3.1 through 3.5 list output elasticities, which reflect the percentage change in quantity demanded that results from a change in industrial sector output. These figures are positive because of the direct relationship between the variables.

Table 3.1. Price and Output Elasticities for Aggregate Energy, Industrial Sector

Study	Data		Price Elasticity ^b		Output Elasticity ^b	
	Type ^a	Vintage	Short-Run	Long-Run	Short-Run	Long-Run
Hudson-Jorgenson (1974)	TS:USA	1947-71		-0.05		1.00 ^c
Berndt-Wood (1975)	TS:USA	1947-71		-0.47		1.00 ^c
Baughman-Zerhoot (1975)	TS-CS: USA	1950-72		-0.22		0.69
Griffin-Gregory (1976)	CS-TS: USA and Europe	1955, '66 1965, '69		-0.79		1.00 ^c
	TS:USA	1947-71	-0.28	-0.42	0.10 ^d	1.00 ^c
Halvorsen (1976c)	TS-CS: USA	1960-72	-0.13	-0.31	1.00 ^c	1.00 ^c
FEA (1976)	USA States					

^a TS refers to time-series data; CS to cross-sectional data; and CS-TS to pooled CS and TS data.

^b Elasticities listed between short-run and long-run columns are ambiguously defined in the reference cited.

^c Value is unity by the assumption

^d This elasticity is not necessarily compatible with the assumption of a Cobb-Douglas production function.

Source: James A. Edmunds, *A Guide to Price Elasticities of Demand for Energy: Studies and Methodologies* (Oak Ridge, Tennessee: Oak Ridge Associated Universities, Institute for Energy Analysis, 1978, ORAU IEA-78-15(R)), p. 14

Table 3.2. Price and Output Elasticities for Electricity, Industrial Sector

Study	Data		Price Elasticity ^b		Output Elasticity ^b		Type ^c of Price
	Type ^a	Vintage	Short-Run	Long-Run	Short-Run	Long-Run	
Fisher-Kaysen (1962)	CS:States	1946-57		-1.25			A
Baxter-Rees (1968)	TS: Indus. U.K.	1954-64	-1.50				A
Anderson (1971)	CS:States	1958, '62		-1.94			A
Mount-Chapman-Tyrrell (1973)	CS-TS: States	1947-70	-0.22	-1.82			A
Lyman (1973)	CS-TS: Areas served by utilities	1959-68	-1.40				A
Griffin (1974)	TS:Aggre- gate U.S.	1951-71	-0.04 ^e	-0.51 ^e			A
Hudson-Jorgenson (1974)	TS:USA	1947-71	-0.07			1.00 ^d	A
Uri (1975)	TS:Monthly Aggregate U.S.		-0.35	-0.69	1.32	2.63	A
Baughman-Zerhoot (1975)	CS-TS: 48 States and Wash., D.C.	1962-72	-0.11	-1.28		0.69	A
Chern (1975a)	CS-TS: 16 U.S. Industries	1959-71	-0.61	-1.98	0.30	0.97	A
FEA (1976)	CS-TS: U.S. Census regions annual	1960-72	-0.15	-1.03	1.00 ^d	1.00 ^d	A
Halvorsen (1976a)	CS:States	1969		-1.24		0.68	M*
Halvorsen (1976b)	CS:USA States	1971		-0.92		1.00 ^d	A

a. TS refers to time-series data; CS to cross-sectional data; and CS-TS to pooled CS and TS data.

b. Elasticities listed between short-run and long-run columns are ambiguously defined in the reference cited.

c. M* refers to a theoretical model in which both average and marginal price elasticities are identical (price data was, however, either A or A*); A to an average price for electricity; and A* to an average price for a fixed amount of electricity.

d. Value is unity by the assumption.

e. Combined industrial and commercial.

Source: James A. Edmonds, *A Guide to Price Elasticities of Demand for Energy: Studies and Methodologies* (Oak Ridge, Tennessee: Oak Ridge Associated Universities, Institute for Energy Analysis, 1978: ORAU/IEA-78-15(R)), p. 16.

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Table 3.3. Price and Output Elasticities for Coal, Industrial Sector

Study	Data		Price Elasticity ^b		Output Elasticity ^b	
	Type ^a	Vintage	Short-Run	Long-Run	Short-Run	Long-Run
Reddy (1974)	TS:USA	1957-73	-0.39	-0.91	0.53	0.60
Hudson-Jorgenson (1974)	TS:USA	1947-71		-0.01		1.00 ^c
Lin-Spore-Nephew (1975)	TS:USA	1957-73		-0.49		0.56
FEA (1976)	CS-TS	1960-72	-0.44 ^d	-0.73 ^d	1.00 ^c	1.00 ^c
	USA					
	States					
Halvorsen (1976b)	CS:USA	1971		-1.52		1.00 ^c
	States					

a. TS refers to time-series data; CS to cross-sectional data; and CS-TS to pooled CS and TS data.

b. Elasticities listed between short-run and long-run columns are ambiguously defined in the reference cited.

c. Value is unity by the assumption.

d. This elasticity refers only to steam coal.

Source: James A. Edmonds, *A Guide to Price Elasticities of Demand for Energy: Studies and Methodologies* (Oak Ridge, Tennessee: Oak Ridge Associated Universities, Institute for Energy Analysis, 1978; ORAU/IEA-78-15(R)), p. 18.

Table 3.4. Price and Output Elasticities for Natural Gas

Study	Data		Price Elasticity ^b		Output Elasticity ^b	
	Type ^a	Vintage	Short-Run	Long-Run	Short-Run	Long-Run
Vermetten-Plantinga (1953)	CS: States	1947		-2.11		
Villanueva (1964)	CS-TS: Regions	1950-60	-1.34 ~ -1.64			
Felton (1965)	CS: States	1961		-1.50 ^c		
Anderson (1971)	CS: States	1958, '62		-1.98		0.21
MacAvoy-Noll (1973)	CS: States			-1.78		0.68
Hudson-Jorgenson (1974)	TS:USA	1947-71	-0.04		1.00 ^d	
Randall-Ives-Ryan (1974)	CS:USA S.W. Communities	1970		-3.85 ^e		0.29 ^e
MacAvoy-Pindyck (1973)	CS-TS: USA States	1964-70	-0.98 ~ -1.13 ^f			
Baughman-Zerhott (1975)	CS-TS: USA States	1962-72	-0.07	-0.81	0.69	

Table 3.4. Price and Output Elasticities for Natural Gas — Continued

Study	Data		Price Elasticity ^b		Output Elasticity ^b	
	Type ^a	Vintage	Short-Run	Long-Run	Short-Run	Long-Run
FEA (1976)	CS-TS: USA States	1960-72	-0.17	-0.58	1.00 ^d	1.00 ^d
Halvorsen (1976b)	CS:USA States	1971		-1.47		1.00 ^d

a. TS refers to time-series data; CS to cross-sectional data; and CS-TS to pooled CS and TS data.

b. Elasticities listed between short-run and long-run columns are ambiguously defined in the reference cited.

c. Elasticity defined for a market share ratio between electricity and natural gas.

d. Value is unity by the assumption.

e. Aggregate commercial and industrial.

f. Saturation elasticity used.

Source: James A. Edmonds, *A Guide to Price Elasticities of Demand for Energy: Studies and Methodologies* (Oak Ridge, Tennessee: Oak Ridge Associated Universities, Institute for Energy Analysis, 1978; ORAU/IEA-78-15(R)), pp. 19-20.

Table 3.5. Price and Output Elasticities for Petroleum

Study	Data		Price Elasticity ^b		Output Elasticity ^b	
	Type ^a	Vintage	Short-Run	Long-Run	Short-Run	Long-Run
Verleger-Sheehan (1974)			-0.12 ^c	-0.61 ^c	0.12 ^c	0.61 ^c
Hudson-Jorgenson (1974)	TS:USA	1947-71		-1.00 ^d -0.02 ^e		1.00 ^{d,h} 1.00 ^{e,h}
Baughman-Zerhoo (1975)	CS-TS: USA States	1962-72	-0.11	-1.32 ^d	0.69 ^d	0.69 ^d
Houthakker-Kennedy (1975)	CS-TS: Nine OECD Countries	1965-70	-0.39 ^c -0.17 ^f -1.05 ^g	-0.76 ^c -2.37 ^f -1.58 ^g	1.43 ^c -0.21 ^f 0.40 ^g	2.70 ^c -2.84 ^f 0.60 ^g
FEA (1976)	CS:USA States	1971	-0.34 ^c -0.26 ^g -0.26 ^f	-1.01 ^c -0.75 ^g -0.75 ^f	1.00 ^{c,h} 1.00 ^{g,h} 1.00 ^f	1.00 ^{c,h} 1.00 ^{g,h} 1.00 ^f
Halvorsen (1976b)	CS:USA	1971		-2.82		1.00 ^h

a. TS refers to time-series data; CS to cross-sectional data; and CS-TS to pooled TS and CS data.

b. Elasticities listed between short-run and long-run columns are ambiguously defined in the reference cited.

c. Elasticities for distillate.

d. Crude petroleum products.

e. Elasticities for gasoline and oil.

f. Elasticity for kerosene.

g. Elasticity for residual oil.

h. Value is unity by the assumption.

Source: James A. Edmonds, *A Guide to Price Elasticities of Demand for Energy: Studies and Methodologies* (Oak Ridge, Tennessee: Oak Ridge Associated Universities, Institute for Energy Analysis, 1978; ORAU/IEA-78-15(R)), p. 21.

Table 3.6 is a matrix of "own," and "cross" elasticities. The concept of "cross" elasticities refers to the responsiveness in the quantity demanded of one fuel to a change in price in another fuel. Thus, "cross" elasticity is a measure of substitutability; if the "cross" elasticity coefficient is positive, the two fuels are substitutes. For example, a coefficient of 0.75 in column 1, row 2, of Table 3.6 implies that, in response to a 10% increase in the price of oil, there is a positive increase of 7.5% in the quantity of gas demanded by industry; the fuels are substitutes. Lower "cross" elasticity coefficients in the second and third columns indicate a lesser degree of substitutability.

Table 3.6. Long-Run Elasticity/Cross-Elasticity Matrix for the Industrial Sector (Less Feedstocks)

Elasticity of Consumption of	In Response to a Price Change at the Point of Consumption in			
	Gas	Oil	Coal	Electricity
Gas	-0.81	0.14	0.15	0.34
Oil	0.75	-1.32	0.14	0.33
Coal	0.75	0.14	-1.14	0.33
Electricity	0.73	0.13	0.14	-1.29

Note: Mean values calculated for the following fuel consumption configuration: 52% natural gas; 19.5% oil; 7.4% coal; 21.1% electricity.

Source: M. L. Baughman and F. S. Zerhout, *Energy Consumption and Fuel Choice by Industrial Consumers in the United States* (Cambridge, Massachusetts: MIT Laboratory, March 1975).

Chapter 5

Investment Criteria and Public Policies Toward Industrial Energy Conservation

by Richard S. Mack

This chapter considers the relationships between investment in industrial energy conservation and public policy measures designed to provide incentives for such investment. In all considerations of policymaking, the relationship between the public and private sectors is of primary importance. Because conservation furthers both private and public goals, it is the role of public policy to assure first that private conservation efforts are allowed to take place to the extent of purely private incentives, and then to extend the degree of conservation beyond the point of private optimality to the point of public sector optimality. Accordingly, this chapter will consider briefly the need for and benefits of conservation and then turn to a discussion of private sector investment criteria, barriers to optimization, and current public sector policies.

I. Conservation

By definition the word *conservation* implies the preservation and management of a limited physical stock. In the industrial sector conservation of fuels can be achieved by four methods of altering energy use patterns:

1. Reduction of energy use through "housekeeping practices" or short-term efficiencies
2. Reduction of use through the retrofitting of energy conservation equipment, not involving process change
3. Reduction of use through process change, a long-run measure

4. Reduction of energy cost by means of fuel substitution and cogeneration

The category of "housekeeping" changes refers to minor modifications of existing systems. These modifications involve leak-plugging in heating and cooling processes, the adjustment of systems not operating at design efficiency, and the employment of energy management techniques to optimize energy use over time, within the constraints of the existing capital structure. Housekeeping measures usually can be accomplished out of operating budgets; capital investment is not necessary. Because relatively low costs and a high rate of dollar savings are associated with the first incremental units of housekeeping changes, internal financial incentives have provided the impetus to initiate these practices.

Retrofitting describes modifications made to existing capital equipment to render it more energy efficient. The modifications are necessary in older equipment because of design inefficiencies, which were appropriate in view of low fuel costs at the time of the original investment. The category of retrofitting also includes some elements of fuel substitution—namely, whatever types of fuel substitution or energy cascading that can be accomplished without completely replacing the process equipment. The level of required investment for retrofitting varies greatly depending upon the nature of equipment purchased.

When investment criteria indicate a financial preference for capital revision over retrofitting operations, the industry may replace existing assets with new ones. These process changes may involve the substitution of new process technology for the pur-

pose of long-run economy in the total costs of operations. Specifically, when retrofitting cannot economically accomplish fuel substitutions, process changes may be necessary. Given the long functional life of capital equipment in major industrial processes, process change requires a major financial commitment, involving decisions that will affect the profits of the firm over decades of use. Table 5.1 shows the age of U.S. manufacturing capacity by sector; note the high percentage of plants that began first-year operations in 1950 or earlier.

Although internal private sector incentives arising from post-1973 energy price increases have led to considerable application of industrial housekeeping measures, all estimates point to further potential efficiencies available through all four measures of conservation. The estimates of industrial energy savings by use of current conservation technology range from 10 to 15%.¹ Tables 5.2 and 5.3 present potential sav-

ings and projected progress for the Voluntary Business Energy Conservation program. In order to realize these potential savings, consideration must be given to decision-making in the private sector and to the way that it is influenced by public sector policies.

II. Investment: Decision-Making in the Private Industrial Sector

The criteria for business investment are multiple and complex. In order to simplify these relationships, it is first necessary to briefly consider the private

1. See C. Berg, "Technical Basis for Energy Conservation," *Technology Review* 76(1974): 14; U.S. Senate, Committee on Commerce, *Energy Waste and Energy Efficiency in Industrial and Commercial Activities* (Washington, D.C.: June 1974); and E. P. Gyftopoulos, et al, *Potential Fuel Effectiveness in Industry* (Cambridge, Massachusetts: Ballinger, 1974).

Table 5.1. Major Industry Groups: Age of Plant, 1975

SIC Code	Industry Group	First Year of Operations Class (%)				
		1950 and earlier	1951—1960	1961—1965	1966—1970	1971—1975
20—39	All manufacturing	57	16	9	11	7
20	Food and kindred products	65	12	8	9	6
21	Tobacco products	81	0	5	4	0
22	Textile mill products	69	8	7	10	6
23	Apparel, other textile products	47	15	12	14	12
24	Lumber and wood products	49	13	11	14	13
25	Furniture and fixtures	54	15	9	11	12
26	Paper and allied products	61	15	9	11	5
27	Printing and publishing	55	14	8	12	10
28	Chemicals, allied products	59	18	7	11	5
29	Petroleum and coal products	82	9	3	4	3
30	Rubber, miscellaneous plastics products	44	15	13	17	10
31	Leather, leather products	59	14	9	12	6
32	Stone, clay, glass products	60	16	9	9	7
33	Primary metal industries	77	10	4	6	4
34	Fabricated metal products	53	17	9	12	9
35	Machinery, except electric	55	16	8	13	8
36	Electric, electronic equipment	41	27	12	13	7
37	Transportation equipment	64	20	6	6	4
38	Instruments, related products	44	21	11	14	11
39	Miscellaneous manufacturing industries	49	0	12	15	0

0 = Withheld to avoid disclosing figures for individual companies.

Source: 1975 Age of Plant File in John Gove, and Cyr Linonis, "Age of Manufacturing Plants," presented at the Joint Statistical Meetings, San Diego, California, 14—17 August 1978

Table 5.2. Potential Savings for 1980^a

SIC Code	Industry	1972 Energy Use (Base Year) 10 ¹² Btu/yr	1980 Energy Use with Base Year Efficiency 10 ¹² Btu/yr	1980 Energy Use Assuming Attainment of Net Targets 10 ¹² Btu/yr	Projected 1980 Savings through Attainment of Net Targets	
					10 ¹² Btu/yr	BFOE/day ^b
20	Food and kindred products	1,047	1,195	1,052	143	62,200
22	Textile mill products	474	567	440	127	55,200
26	Paper and allied products	1,388	1,526	1,210	316	137,400
28	Chemical and allied products	3,087	4,800	4,128	672	292,200
29	Petroleum and coal products	2,993	4,007	3,527	480	208,700
32	Stone, clay, and glass products	1,462	1,753	1,478	275	119,600
33	Primary metal industries	4,246	5,167	4,690	477	207,400
34	Fabricated metal products	442	587	445	142	61,800
35	Machinery, except electric	437	707	601	106	46,100
37	Transportation equipment	414	690	580	110	47,800
	Total	15,990	20,999	18,151	2,848	1,238,400

a. In terms of total energy use.

b. Barrels fuel oil equivalent (BFOE) per day; conversion factor is 6.3×10^6 Btu per BFOE.Source: U.S. Department of Energy, *Industrial Energy Efficiency Program, Annual Report* (Washington, D.C.: 31 March 1978).

Table 5.3. Progress toward Achieving Energy Conservation Goals

SIC Code	Industry	Percent Improvement in Energy Efficiency	
		Realized 1976	Target 1980
20	Food	11	12
22	Textiles	12	22
26	Paper	9	20
28	Chemicals	10	14
29	Petroleum	10	12
32	Stone, clay, glass	8	16
33	Primary metals	4	9
34	Fabricated metals	8	24
35	Machinery	19	15
37	Transportation	13	16
	Composite average	8	13

Source: U.S. Department of Energy, *Industrial Energy Efficiency Program, Annual Report* (Washington, D.C.: 31 March 1978).

sector. Goal-setting in industry is in itself a complex process; the long-run viability of a firm may depend upon the ability of management to shift emphasis in the short run from one managerial objective to another.

The traditional private sector organizational objective is profit maximization, which is likely to be the most appropriate single goal in the long run. Yet this objective is usually constrained by other parameters, which include the maintenance of market share, the maintenance of stockholder rate of return, the maintenance of sales levels, and the minimization of risk. Alternatively, each of those constraints can become a goal in its own right, particularly in the short run. Such goal substitution would, therefore, shift profitability into the category of a parameter, requiring a stated level of profitability to satisfy stockholders or management.

Assuming a long-run criterion of profit maximization, investment decisions about the purchase of equipment for either retrofitting or process change depend upon expectations of the long-term effect of these expenditures on the cash flows of the firm. Most capital budgeting models consider the contribution

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of a capital asset to the long-term profitability of the firm: that is, if, over the lifetime of an investment, the additional benefits outweigh the marginal costs, then the investment is deemed acceptable. Specifically, the marginal benefits of an energy-related investment may include reduction in fuel costs over time, as well as favorable changes in other input/output relationships; the marginal costs include such incremental costs to the firm as capital, operating, and maintenance charges. Both benefits and costs are adjusted for the length of time of the analysis by incorporating some version of present valuation. In view of the likelihood that, over time, both benefits and costs will vary from original expectations, assorted adjustments for decision-making under uncertainty may be incorporated into this capital budgeting framework. Analytic techniques for investment analysis are variations and extensions of this basic marginal analysis. These techniques include internal rate of return analysis, break-even analysis, payback analysis, and life-cycle costs analysis. In combination with present valuation and risk assessment theories, all of these methods allow for ranking and choosing among investment alternatives.

Despite the apparent simplicity of this general approach, numerous factors enter into the calculation of comparative feasibility; many of these variables are based upon the decision-makers' perceptions of the future. A partial list of these contributing factors include the following:

- Expected product demand
- Expected changes in the cost of capital
- Expectations of fuel cost and availability
- Interaction with regulatory requirements
- Age of existing process equipment
- Change in unit costs
- Operating and maintenance expenses
- Tax advantages
- Installation disruption

Among these factors are several influenced by external institutions. Because of the importance of these institutions to the investment decision, a brief consideration of situations in which these factors become barriers is necessary to the development of policy analysis.

III. Barriers

With respect to investment in energy conservation equipment, the term *barriers* refers to those con-

straints on the investment decision that are raised by the regulations, policies, or procedures of institutions in both the public and private sectors. Thus, environmental regulation would be an example of a barrier to certain fuel substitution measures. Similarly, barriers are raised by the policies of financial institutions, which offer different interest rates depending upon the purpose and the time horizon of the loan. Because the general field of energy production is highly regulated, numerous barriers are unintentionally raised by state, federal, and local power regulatory boards against private sector cogeneration when requirements originally established for commercial electrical generation are applied to generation for internal use.²

Reducing and avoiding such barriers are goals of policymakers. As information is a primary requisite to attaining that goal, studies are under way to identify the sources of barriers to industrial investment in conservation. A recent study by the Lawrence Berkeley Laboratory has developed a method of identifying potential barriers to investment by analyzing the interaction of attributes of various conservation measures with the characteristics of the industry.³

Figures 5.1 through 5.6 treat several conservation measures considered as potential investments by the steel and chemical industries. Each table is a matrix that expresses industrial sector characteristics as row variables and attributes of the conservation measure as column variables. The industrial sector characteristics are factors that have significant bearing upon the investment decision; these characteristics are described for the particular industry as of "high, medium, or low" (H, M, or L) importance. Similarly, the column variables of conservation measure attributes are rated "high, medium, or low" depending upon qualitative determination. Each cell contains a sign for plus, minus, or zero. These represent the resultant interaction of conservation measure attributes and industrial sector characteristics. Plus indicates a combination of factors that increases the likelihood of adoption. Minus denotes the decreased likelihood of the adoption of the measure, and zero denotes the lack of significant effect.⁴ Examination of the matrix will determine whether the given conservation

2. G. N. Hatsopoulos, E. P. Gyftopoulos, et al, "Capital Investment to Save Energy," *Harvard Business Review* (March-April 1978).

3. Lawrence Berkeley Laboratory, *Energy Conservation: Policy Issues and End-Use Scenarios of Savings Potential*, Part 3: *Policy Barriers and Investment Decisions in Industry* (Berkeley: University of California, September 1978).

4. LBL, *Energy Conservation*, p. 11.

Conservation Measure Attribute Subsector Characteristics	Cost Effective H M L	Relative Cost H M L	Unreliability Unscheduled Downtime H M L	Disruption to Install H M L	Technical Sophistication Needed H M L	Environmental Impacts + 0 -	Change in Dependency + 0 -
Market Growth H M L	0	0	0	0	0	0	0
Capital Intensity H M L	+	-0	0	0	0	0	0
Energy Intensity H M L	+	0	0	0	0	0	0
Access to Credit H M L	0	0	0	0	0	0	0
Rate of Return on Investment H M L	0	0	0	0	0	0	0
Regulatory Restrictions H M L	0	0	0	0	0	0	0
Age of Plant (old) H M L (new)	+	-	0	0	0	0	0
Availability of Fuels H M L	0	0	0	0	0	0	0
Technical Complexity H M L	0	-	0	-	-	0	0

Figure 5.1. Conservation/investment matrix for improved housekeeping in the steel industry

Source: Lawrence Berkeley Laboratory, *Energy Conservation: Policy Issues and End-Use Scenarios of Savings Potential, Part 3: Policy Barriers and Investment Decisions in Industry* (Berkeley: University of California, September 1978), p. 14.

measure faces significant barriers, which might require government action.⁵

Government action is both a potential creator and a potential remover of barriers to investment. Accordingly, the following section describes a theory of optimality of government actions. The various policy measures that currently influence the decision to invest in industrial energy conservation are then briefly described in the review of existing legislation.

IV. Public Policies Affecting Energy Consumption

Energy-related public policy encompasses the group of laws, taxes, incentives, or rules by which the public sector alters the level of energy use that results from a purely private sector equilibrium. It is empha-

5. LBL, *Energy Conservation*, p. 12.

Conservation Measure Attribute Subsector Characteristics	Cost Effective H M L	Relative Cost H M L	Unreliability Unscheduled Downtime H M L	Disruption to Install H M L	Technical Sophistication Needed H M L	Environmental Impacts + 0 -	Change in Dependency + 0 -
Market Growth H M L	-	-	0	0	0	0	0
Capital Intensity H M L	-	-	0	0	0	0	0
Energy Intensity H M L	+	0	0	0	0	+	0
Access to Credit H M L	+	+	0	0	0	0	0
Rate of Return on Investment H M L	-	0	0	0	0	0	0
Regulatory Restrictions H M L	-	-	-	-	-	+	0,-
Age of Plant (old) H M L (new)	+	+	0	0	0	+	0
Availability of Fuels H M L	+	0	+	0	0	+0	+0
Technical Complexity H M L	-	-	-	-	-	0	0

Figure 5.2. Conservation/investment matrix for new plant construction in the steel industry

Source: Lawrence Berkeley Laboratory, *Energy Conservation: Policy Issues and End-Use Scenarios of Savings Potential*, Part 3: *Policy Barriers and Investment Decisions in Industry* (Berkeley: University of California, September 1978), p. 15.

sized that, in theory, intervention occurs and is justified when conditions in the private sector do not allow for equilibrium levels of energy use, conservation, and supply deemed adequate by public bodies. Such an inefficient situation may result from imperfections in the institutions and activities associated with the internal incentives of the price system.

When the private sector solution is less than optimal, movement toward a more preferable equilibrium can be effected by policies that either (1) alter the private sector solution by making marginal changes in the price system inputs, or (2) provide a substitute for the private sector solution. In either case, the

general theory of public decision-making closely parallels that of the private sector in the consideration of the incremental benefits and costs of public actions.⁶ The existence of positive net benefits indicates feasibility of a policy action. The general formula for policy optimization is the present value expression,

$$\text{Net benefits} = \sum_{t=1}^n \frac{\Delta \text{Efficiency} + \Delta \text{Equity}}{(1+i)^t} - \sum_{t=1}^n \frac{\Delta \text{Costs}_a + \Delta \text{Costs}_b}{(1+i)^t}$$

6. For a survey of benefit-cost techniques, see Alan R. Prest and Ralph Turvey, "Cost-Benefit Analysis: A Survey," *Economic Journal* (1965): 683-735.

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Conservation Measure Attribute Subsector Characteristics	Cost Effective H M L	Relative Cost H M L	Unreliability Unscheduled Downtime H M L	Disruption to Install H M L	Technical Sophistication Needed H M L	Environmental Impacts + 0 -	Change in Dependency + 0 -
Market Growth H M L	+0	0	0	0,-	0	0	0
Capital Intensity H M L	+0	0	0	0,-	0	0	0
Energy Intensity H M L	+0	0	0	+0	0	0	0
Access to Credit H M L	0	0	0	0	0	0	0
Rate of Return on Investment H M L	0	0	0	-	0	0	0
Regulatory Restrictions H M L	+0	0	0	0	0	+0	0
Age of Plant (old) H M L (new)	0,-	+0	0	0	0	+	0
Availability of Fuels H M L	0	0	0	0	0	0	0
Technical Complexity H M L	+	-	0	-	-	0	0

Figure 5.3. Conservation/investment matrix for improved housekeeping in the chemicals industry

Source: Lawrence Berkeley Laboratory, *Energy Conservation: Policy Issues and End-Use Scenarios of Savings Potential, Part 3: Policy Barriers and Investment Decisions in Industry* (Berkeley: University of California, September 1978), p. 16.

where $costs_p$ and $costs_o$ represent public and private costs, and the denominators of the aggregate benefit and aggregate cost expressions indicate present valuation of the n periods of policy existence based upon a rate of time discount i .⁷ A theoretical optimum is achieved when all policy prescriptions have equal net marginal yields, and system net benefits are accordingly maximized. Much like private sector criteria, adjustments are made to discount not only for time elements, but also for the relative probabilities of actualizing projected benefits and costs. This model of public policy is only an idealized reflection of reality, yet, like the friction-free model of the perfectly

competitive economy, it provides concepts of causality and offers a measure of efficiency to which reality can be compared.

V. Review of Existing Legislation

There are three general types of policy measures that directly affect industrial energy use: tax incentives, direct regulation, and subsidies. Existing policies of each type are listed and briefly described below.

7. Clair Wilcox and W. G. Shepard, *Public Policies Toward Business* (Homewood, Illinois: Richard D. Irwin, Inc., 1975), p. 51.

Conservation Measure Attribute Subsector Characteristics	Cost Effective H M L	Relative Cost H M L	Unreliability Unscheduled Downtime H M L	Disruption to Install H M L	Technical Sophistication Needed H M L	Environmental Impacts + 0 -	Change in Dependency + 0 -
Market Growth H M L	+	+	0	0	0	0	0
Capital Intensity H M L	-	-	0	0	0,-	0	0
Energy Intensity H M L	+	0	0	0	0	+	+
Access to Credit H M L	+	+	0	0	0	0	+0
Rate of Return on Investment H M L	+	0	0	0	0	0	0
Regulatory Restrictions H M L	-	-	0	0,-	0,-	-	0,-
Age of Plant (old) H M L (new)	-	-	0	0	0	0	0
Availability of Fuels H M L	+, -	0	0	0	0	0	0
Technical Complexity H M L	+	-	-	-	-	0	0

Figure 5.4. Conservation/investment matrix for new plant construction in the chemicals industry

Source: Lawrence Berkeley Laboratory, *Energy Conservation: Policy Issues and End-Use Scenarios of Savings Potential, Part 3: Policy Barriers and Investment Decisions in Industry* (Berkeley: University of California, September 1978), p. 17.

The chronological ordering of public laws (PL) underscores the acceleration of industrial conservation enactments. This list covers only federal legislation that has significant, direct or indirect impact on industrial energy use.⁸

A. 1974

1. Energy Supply and Environmental Coordination Act (PL 93-319)

This act involved conversion of power plants to coal and required several areas of study by the Federal Energy Administration (FEA) concerning restric-

tion of export of energy-intensive goods, incentives for increased industrial recycling, and industrial energy use efficiencies.

2. Nonnuclear Energy Research and Energy Research and Development Act (PL 93-577)

This act required that "energy conservation shall be a primary consideration in the design and implementation of the federal nonnuclear energy programs."

8. The review of energy conservation legislation relies upon Doan L. Phung, "Energy Conservation Policies," unpublished manuscript, Oak Ridge Associated Universities, Institute for Energy Analysis, Oak Ridge, Tennessee, 1978; and Congressional Quarterly, Inc., *Energy Policy* (Washington, D.C.: April 1979).

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Conservation Measure Attribute Subsector Characteristics	Cost Effective H M L	Relative Cost H M L	Unreliability Unscheduled Downtime H M L	Disruption to Install H M L	Technical Sophistication Needed H M L	Environmental Impacts + 0 -	Change in Dependency + 0 -
Market Growth H M L	+	+	0	-	0	0	0
Capital Intensity H M L	-	+	0	-	0	0	0
Energy Intensity H M L	+	-	0	0	0	+	0
Access to Credit H M L	0	+	0	0	+	0	0
Rate of Return on Investment H M L	-	+	0	0	0	0	0
Regulatory Restrictions H M L	0,-	0,-	+0	0	0,-	0,-	0
Age of Plant (old) H M L (new)	+,-	+	+	0,-	0	0	0
Availability of Fuels H M L	+,-	+,-	0	0	+,-	+,-	+,-
Technical Complexity H M L	-	0,-	+	-	-	0	0

Figure 5.5. Conservation/investment matrix for waste heat recovery in the chemicals industry

Source: Lawrence Berkeley Laboratory, *Energy Conservation: Policy Issues and End-Use Scenarios of Savings Potential, Part 3: Policy Barriers and Investment Decisions in Industry* (Berkeley: University of California, September 1978), p. 18.

B. 1975

The Energy Policy and Conservation Act (PL 94-163) required that the FEA establish efficiency targets in each of the 10 most energy-consuming sectors. The program was voluntary with no penalties for failure to reach the targets.

C. 1976

Under the Energy Conservation and Production Act (PL 94-385), the FEA was authorized to study electric utility rate design changes with respect to the effects of peak pricing, load management, etc.

D. 1978

The 1978 National Energy Act is comprised of five bills, each having impact upon the industrial sector:

The Powerplant and Industrial Fuel Use Act (PL 95-620)

The Energy Tax Act (PL 95-618)

The Public Utility Regulation Policies Act (PL 95-617)

The Natural Gas Policy Act (PL 95-621)

The National Energy Conservation Policy Act (PL 95-619)

Conservation Measure Attribute Subsector Characteristics	Cost Effective H M L	Relative Cost H M L	Unreliability Unscheduled Downtime H M L	Disruption to Install H M L	Technical Sophistication Needed H M L	Environmental Impacts + 0 -	Change in Dependency + 0 -
Market Growth H M L	+	+	0	0	0	0	0
Capital Intensity H M L	-	-	0	+,-	-	0	0
Energy Intensity H M L	+	-	0	0	0	+	0
Access to Credit H M L	-	-	0	0	0	0	0
Rate of Return on Investment H M L	0	0	0	0	0	0	0
Regulatory Restrictions H M L	-	-	+,-	0	0,-	-	0,-
Age of Plant (old) H M L (new)	+	+	0	0	0	0	0
Availability of Fuels H M L	+,-	+,-	+,-	+0-	+,-	+,-	0
Technical Complexity H M L	+	-	-	0,-	0,-	0	0

Figure 5.6. Conservation/investment matrix for process change and major renovation in the chemicals industry

Source: Lawrence Berkeley Laboratory, *Energy Conservation: Policy Issues and End-Use Scenarios of Savings Potential, Part 3: Policy Barriers and Investment Decisions in Industry* (Berkeley: University of California, September 1978), p. 19.

1. Powerplant and Industrial Fuel Use Act

Title II barred new electric power plants and major fuel-burning installations from using fuel oil or natural gas as the primary energy source in large boilers. The energy secretary was also empowered to issue rules prohibiting oil and gas use in broad categories of non-boiler uses. Temporary exemptions could be obtained, however, on grounds of environmental constraints or in cases of the physical incapability of conversion; provision for permanent exemption was also made.

Title III dealt with existing facilities, prohibiting the burning of natural gas after 1990; plants not using gas as a primary fuel during 1977 were prohibited from converting to gas. Title IV empowered the energy secretary to prohibit the space heating use of natural gas if the boiler consumed 300,000 cubic feet of gas per day and could run on oil. Title IV, Section 602, authorized \$400 million in both 1979 and 1980 for loans to existing power plants to finance the cost of pollution control devices required for coal conver-

sion, and Title VII created programs to study the effects of increased coal use.

2. Energy Tax Act

A 10% investment tax credit was provided to businesses for the installation of (1) equipment for producing synthetic fuel, geothermal, solar, or wind energy if installed in a new building; (2) heat exchangers, waste heat boilers, heat wheels, recuperators, heat pipes, automatic energy control systems, and other specified items for industrial energy conservation in process uses; and (3) specified industrial recycling equipment, shale oil equipment, and equipment used to produce natural gas from geopressured brine. Moreover, the act provided special depreciation treatment for natural gas or oil boilers replaced before their expected retirement and a percentage depletion allowance for natural gas produced from geopressured brine. It also denied investment tax credit and accelerated depreciation for specified gas and oil boilers.

3. Public Utility Regulatory Policies Act

The primary effect of this act involved the impact of rate structure changes upon industrial electricity rates. These provisions required the prohibition of declining block rates and the encouragement of seasonal rates, time-of-day rates, interruptible rates, load management techniques. Other sections of the act that affect industry are as follows:

Title II, Section 210, provided for the encouragement of cogeneration and small-scale power production by establishing rules which required utilities to sell electricity to and purchase electricity from qualifying cogenerational facilities.

Title IV encouraged industrial development agencies to develop small hydroelectric projects. Loans were made available for feasibility studies and for licensing costs.

4. Natural Gas Policy Act

A number of the provisions of this act potentially influence industrial energy use. The act required an incremental pricing rule for industrial boiler fuel facilities, which identified those low-priority gas consumers who would bear the higher costs for purposes of easing the impact on high-priority users. Furthermore, once an incrementally priced industrial facility reached gas prices equal to an alternate fuel's, the higher gas costs would be limited to the alternative fuel price level. Title IV of the act specified certain

industrial processes or feedstock uses that have curtailment priorities after residences, businesses, schools, and hospitals.

5. The National Energy Conservation Policy Act

Although directed primarily at houses and businesses, this act did make provision for the establishment of industrial equipment efficiencies and recycling targets. It also provided for the testing and labeling of energy efficiencies in specified process heat, electrolytic, and electric motor-driven equipment and set targets for the use of recycled materials in the metals, paper, textile, and rubber industries.

VI. Policy Assessment

Assessment of industrial energy policy not only involves the appraisal of past and existing policy efforts but also can establish relationships upon which projection of future policy actions may be based. Policy analysis is, therefore, an ongoing process by which the gap between theory and reality can be narrowed.

Because the preponderance of existing federal conservation legislation was enacted in the fall of 1978, many associated policy directives have only recently been issued. Under these conditions, impact assessment is premature. In the absence of such appraisals, policy impact projections can only be based upon the effectiveness of parallel or general policy issues. For example, projections of the effectiveness of the industrial energy tax policies may be based upon the substantial literature which deals with the general response of industrial investment to tax policy.⁹ Based on this type of response, simulations can be developed to estimate the impact of the explicit energy policy.

This chapter does not attempt to enumerate the vast number of state and local policies enacted since 1974. The relationship between these state and local policies and federal legislation does merit study, particularly because of the possible existence of conflicting as well as complementary relationships.

9. See Robert Eisner and Patrick Lawler, "Tax Policy and Investment: An Analysis of Survey Responses," *American Economic Review* 65, no. 1 (March 1975); R. E. Hall and D. W. Jorgenson, "Tax Policy and Investment Behavior," *American Economic Review* (June 1967); and G. Fromm, ed., *Tax Incentives and Capital Spending* (Washington, D.C.: The Brookings Institution, 1971).

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Chapter Eight

THE PRICE SENSITIVITY OF THE HUNGARIAN ECONOMY: THE CASE OF ENERGY DEMAND

BY ISTVAN DOBOZI

Introduction

In the past decade considerable research effort has been expended to understand the terms of trade and balance of payments effects of the dramatic increases in energy import prices on the Hungarian economy. However, comparatively little attention has been devoted to the effects of the domestic energy price changes, although pricing has increasingly been used as an instrument of energy policy in an attempt to reduce energy demand and encourage conservation.

The aim of this chapter is to estimate empirically the responsiveness of users to these changes in domestic energy prices. Knowledge of this is important on several grounds:

(i) A high price elasticity for energy demand implies a long-term ability of the economy to absorb the impact of higher energy prices; price shocks, after generating pronounced inflationary and recessionary effects in the short term, do not act as a constraint to economic growth over the longer term. By contrast, a low price elasticity implies weak reactions to increasing energy costs and a protracted adverse effect on output, inflation and other macro-economic variables.¹

(ii) The size of the price elasticity allows us to assess the feasibility of energy conservation through price-induced effects.

(iii) Study of price sensitivity may shed light on potential systemic or regulatory problems of a more general nature.

Our procedure is to estimate a series of demand models for various energy products and consuming sectors for which data were available. We believe that simultaneous models are inappropriate and generally lead to biased estimates because they do not take account of the dynamic nature of energy demand, equipment depreciation and inter-factor substitution. Two types of dynamic model are used for estimating short-run and long-run price elasticities, namely the autoregressive Koyck scheme and the Almon polynomial lag scheme.

The variety and severity of estimation problems show that it is no simple matter to estimate price elasticities and that it is equally difficult to assess the reliability of the estimates when they have been made. Comparisons of estimation procedures indicate that potentially large discrepancies may occur as a result of choices among competing models, estimators and data.²

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Uncertainty about the accuracy of a specific elasticity measurement can be somewhat mitigated if the results of alternative models are compared. Such a comparison reveals a range of elasticities with which one can feel more confident than with any one elasticity measurement.

First we present the dynamic models and discuss some estimation problems. Then we give the estimation results and some international comparisons. Finally, we discuss some of the factors responsible for the relatively price-inelastic response in the Hungarian productive sectors.

The model methodology

It is assumed that the simple static version of the energy consumption function has the following general form:

$$E_t = a + bY_t + cP_t + e_t \quad (1)$$

where E = energy consumption
 Y = real Gross Domestic Product
 P = real price of energy
 e = error term
 a = constant

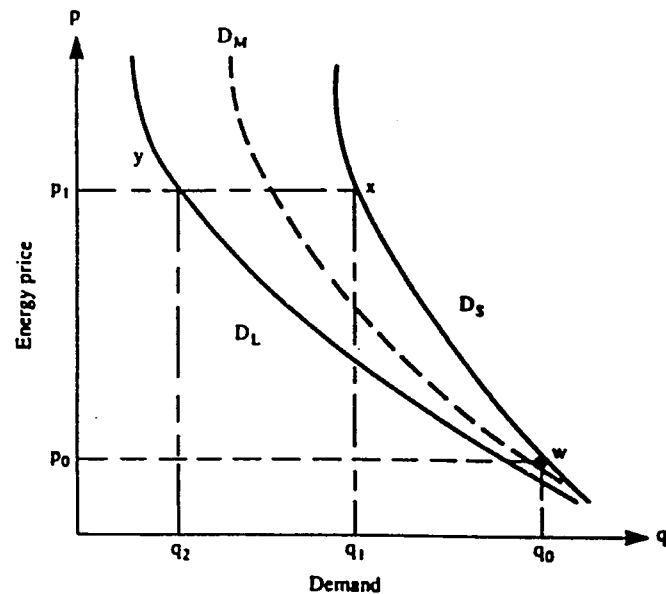
The variables are expressed in logarithms, so that b is the income elasticity and c is the short-run price elasticity. Unless stated otherwise, we shall assume that the error term is normally distributed, independent of the explanatory variables, and neither serially correlated nor heteroscedastic.

The usual deficiency of static models such as (1) is that they do not allow for any long-term reaction to price changes. Change in the demand for energy sources is a dynamic process because reactions are not complete within a single time period. Consumers' immediate response to a price change is limited to more or less use of available energy-using devices. For example, firms are locked into existing capital structures and production processes, limiting their reaction to energy price changes to more or less intensive use of existing capital.³ Until the capital stock is altered through depreciation, modification, and replacement, energy demand will be relatively little affected by price changes independent of income level changes, and thus relatively price-inelastic responses can be anticipated.

An increase in the real price of energy generates conservation trends that will last for a longer period of time. A restructuring of the capital stock (including modifications to existing equipment), inter-factor substitution, the gradual phasing out of energy-intensive processes, etc., are the elements embedded in the long-term price elasticity. Thus it is anticipated that consumer responses to energy price changes will spread out over several years.

The contrast between short- and long-run elasticities can be visualised as a shift in the demand curve. Take a situation shown in Figure 1, where the energy price suddenly rises from p_0 to p_1 . In the short run there is only a small

FIGURE 1 SHORT-RUN AND LONG-RUN ELASTICITIES



decrease in demand from q_0 to q_1 , as consumption moves up on a (constant-elasticity) short-run curve D_S from w to x . However, this is only a partial response, and the total response may be expected to cumulate over time as a result of substituting other inputs, such as labour and capital, for energy, by adopting technical changes, etc. Thus demand would continue moving toward q_2 , which is on the long-run demand curve D_L . This movement can be depicted as going from x to y ; a large number of demand curves are being crossed, one of which is the intermediate demand curve D_M .

It is not unusual in the literature to assume a dynamic relationship between energy consumption and income changes, in addition to this dynamic relationship between price and consumption. However, the same dynamic mechanism does not really apply in the case of income elasticity.⁴ The income effect operates on energy demand through the utilisation of energy-using equipment. High past incomes (unlike past prices) do not have a bearing on current energy demand. Past incomes may determine the capital stock in industry and appliances in the household, but there is no guarantee that these will be fully used at any given point in time. It is the movement in current income that, by determining the utilisation rates, establishes the level of energy demand (along with prices and other factors). Thus income represents the capacity utilisation variable and hence has only a short-term impact, while price changes have both a short and a long-run impact on energy consumption. Energy demand is then assumed to be a function of income (activity level) and prices according to the following double-logarithmic specification:

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$$E_t = a + bY_t + c_0P_t + c_1P_{t-1} + c_2P_{t-2} + \dots + c_l$$

$$= a + bY_t + \sum_{j=0}^{\infty} c_j P_{t-j} + e_t \quad (2)$$

where a , b and c are the parameters to be estimated. c_0 is the short-run price elasticity and c_1, c_2, \dots are the interim price elasticities because they measure the impact on mean E of a unit change in P in various time periods. And

$$\sum_{j=0}^{\infty} c_j$$

gives the long-run price elasticity.

Model (2) represents an infinite lag distribution because the length of the lag is assumed to be infinite. In some cases it is reasonable to assume that

$$\lim_{j \rightarrow \infty} c_j = 0$$

$$j \rightarrow \infty$$

The vanishing of the c_j in the limit means that following a change in the explanatory variable P , the dependent variable E eventually reaches, perhaps in asymptotic fashion, a new equilibrium. If all c_j after c_m vanish, the model reduces to a finite distributed lag of the following form:

$$E_t = a + bY_t + \sum_{j=0}^m c_j P_{t-j} + e_t \quad (3)$$

The infinite distribution lag model is clearly not suitable for direct estimation in its original form since it involves an infinite number of regressors. If the number of terms in the finite distributed lag is very small, then model (3) can be estimated using ordinary least-squares (OLS) regression. However, when there are many terms and little is known about the form of the lag, direct estimation becomes difficult for several reasons. First, the estimation of a lengthy lag structure uses up a large number of degrees of freedom. Second, the estimation of an equation with a substantial number of lagged explanatory variables is likely to lead to imprecise parameter estimates because of the presence of multicollinearity. Both these difficulties can be resolved if one can specify *a priori* some conditions about the form of the distributed lag. Many possible structures for the lagged coefficients have been suggested in the econometric literature.⁵ In this chapter we use two of these, the Koyck and the Almon distributed lag models.

The Koyck model assigns increasingly lower weight or importance to

energy price in past time periods in the form of a series of geometrically declining weights. With appropriate transformation model (3) can be estimated by Ordinary Least Squares (OLS) in the following form:

$$E_t - E_{t-1} = a(1-\lambda) + b(Y_t - \lambda Y_{t-1}) + c_0 P_t + \lambda E_{t-1} + v_t \quad (4)$$

where b is the short-run income elasticity, c_0 is the short-run price elasticity, and v_t is the error term. The long-run elasticity is given by $c_0/(1-\lambda)$, where λ is the rate of decline of the distributed lag.

The Almon model allows a more flexible distributed lag. Here we assume that lag weights can be specified by a continuous function, which in turn can be approximated by evaluating a polynomial function at the appropriate discrete points in time.

Suppose that the lag pattern can be approximated by a polynomial of the following form:

$$c_i = w_0 + w_1 i + w_2 i^2 + \dots + w_p i^p \quad (5)$$

where p is the degree of the polynomial. The length of the lag may be defined as the number of c 's excluding c_0 . With appropriate transformation we obtain the following model in which the parameters a , b and w can be estimated by OLS.

$$E_t = a + bY_t + w_0 \left(\sum_{i=0}^j P_{t-i} \right) + w_1 \left(\sum_{i=1}^j iP_{t-i} \right) + w_2 \left(\sum_{i=1}^j i^2 P_{t-i} \right) + \dots + w_p \left(\sum_{i=1}^j i^p P_{t-i} \right) + e_t \quad (6)$$

where b is the short-run elasticity and the price elasticities can be calculated from (5).

Estimation results

Time series data were collected for the whole economy and for three sectors, industry, agriculture and households, on the direct consumption (direct consumption excludes consumption related to converting one source of energy into another one) of aggregate energy and several energy sources such as oil, natural gas, coal, electricity, heating oil and petrol. When energy demand is analysed at the aggregate level, many important shifts within the structure of the economy are concealed. Energy demand behaviour should also be modelled at the sectoral level, where the different profile of adjustments can more properly be investigated. The sectoral scope and the number of fuels investigated for the individual sectors were determined by the availability of data.

The income (or activity) variable represents real GDP for the national economy and real sectoral value added for industry and agriculture. Real values were obtained by using the industrial producer price index as deflator. In the case of the household sector the income variable is represented by real income using the general consumer price index as deflator.

Energy prices are expressed in real terms using the industrial producer price index as deflator for the whole economy, industry and agriculture, and the general consumer price index for the household sector. Average energy prices used in the aggregate energy demand models represent a Btu-weighted average of different fuel price categories. In several models, to test the effects of winter temperature, the average winter temperature is introduced. All the models are specified in double-logarithmic form so that the estimated parameters of the explanatory variables can be interpreted as elasticities.

Different degree polynomials with various lengths for the price lag were

TABLE 1
AGGREGATE ENERGY CONSUMPTION

Estimation period Lag structure	Whole Economy			Industry	Agriculture
	1970-84 Static	1970-84 Koyck	1970-84 Almon linear	1970-84 Almon linear	1970-84 Static
Total length (in years) of lag distribution Parameter ^{(1), (2)}	0	∞	4	3	0
a	1.494 (4.112)	0.942 (2.621)	-0.985 (1.214)	-0.313 (0.584)	0.278 (0.152)
b	0.767 (7.197)	0.987 (4.670)	1.610 (7.075)	1.255 (9.002)	1.068 (1.974)
c_0	-0.092 (1.911)	-0.049 (2.247)	-0.096 (3.271)	-0.048 (1.803)	-0.065 (0.337)
c_1			-0.085 (4.480)	-0.057 (4.411)	
c_2			-0.074 (5.325)	-0.057 (5.365)	
c_3			-0.063 (3.330)	-0.076 (2.979)	
c_4			-0.052 (1.786)		
$\sum d$	-0.030 (1.963)	-0.160 (2.576)	-0.318 (1.431)	-0.248	-0.011 (0.289)
R^2	0.972 ⁽³⁾	0.712	0.895	0.913	0.522
D.W.	1.702 ⁽⁴⁾	1.830 ⁽⁵⁾	2.231	2.668	0.741

Notes: ⁽¹⁾ a =constant term; b =short run income/activity/elasticity; c_0 =short-run price elasticity; c_1, c_2, c_3, c_4, c_5 =lagged price elasticities; $\sum c_i$ =long-run price elasticity (significant coefficients only); d =weather elasticity;

⁽²⁾ t-ratios in parentheses;

⁽³⁾ Unadjusted for degrees of freedom;

⁽⁴⁾ The estimates were corrected for serial correlation;

⁽⁵⁾ The Durbin-Watson statistic is reported, although biased toward 2 in the presence of lagged dependent variable, for lack of any more relevant statistic.

tried when the Almon technique. That particular polynomial lag profile is chosen which provides the best (in the statistical sense) fit. Generally this is a linear structure. In those cases when only one dynamic model is reported the other model's overall explanatory power proved to be too low, as indicated by a low F-statistic. Initially, cross-price elasticities were also estimated, but in all cases they proved to be statistically insignificant and frequently had the wrong (negative) sign. Since price-driven inter-fuel substitution was found to be negligible, only own-price elasticities are to be estimated. The results of the estimation are given in Tables 1-7, and the price elasticity estimates obtained with alternative models are summarised in Table 8.

Generally speaking, as anticipated, the static formulation of the demand for energy is unsatisfactory. Although the static model generally gives an excellent fit to the data, the strong evidence of serial correlation indicated by the Durbin-Watson test suggests that this model is not well specified. Most of the computed yearly price elasticities are far too big, mainly because they absorb part of the missing long-term price effect. Similarly, as a consequence

TABLE 2

OIL CONSUMPTION OF INDUSTRY

Estimation period Lag structure	1960-84 Static	1960-84 Koyck	1960-84 Almon linear
Total length (in years) of lag distribution Parameter ⁽¹⁾ , ⁽²⁾	0	∞	5
a	-1.649 (5.851)	-0.289 (1.689)	-2.506 (8.347)
b	1.539 (18.751)	1.561 (7.376)	1.827 (24.480)
c ₀	-0.211 (5.618)	-0.052 (3.536)	-0.083 (3.549)
c ₁			-0.074 (5.265)
c ₂			-0.064 (10.734)
c ₃			-0.055 (6.585)
c ₄			-0.045 (2.629)
c ₅			-0.036 (1.335)
$\sum c_i$		-0.277	-0.321
R ²	0.974	0.731	0.984
D.W.	0.920	1.723 ⁽³⁾	1.738

Notes: ⁽¹⁾ a=constant term; b=short-run income (activity) elasticity; c₀=short-run price elasticity; c₁, c₂, c₃, c₄, c₅=lagged price elasticities; $\sum c_i$ =long-run price elasticity (significant coefficients only);

⁽²⁾ t-ratios in parentheses;

⁽³⁾ The Durbin-Watson statistic is reported, although biased toward 2 in the presence of lagged dependent variable, for lack of any more relevant statistic.

TABLE 3

NATURAL GAS CONSUMPTION

Estimation period Lag structure	Industry		Households		
	1963-84 Static	1963-84 Almon quadratic	1963-84 Static	1963-84 Koyck	1963-84 Almon linear
Total length (in years) of lag distribution Parameter ⁽¹⁾ , ⁽²⁾	0	4	0	∞	5
a	-5.516 (2.635)	-1.489 (3.425)	-8.887 (1.547)	6.807 (1.573)	23.572 (2.640)
b	2.123 (4.774)	1.441 (16.041)	4.251 (10.023)	2.531 (3.880)	2.156 (2.996)
c ₀	0.135 (1.024)	0.156 (3.052)	-1.378 (1.596)	-2.237 (3.311)	-0.767 (2.009)
c ₁		0.029 (0.986)			-0.874 (3.175)
c ₂		-0.041 (1.066)			-0.981 (4.596)
c ₃		-0.053 (1.913)			-1.088 (4.634)
c ₄		-0.007 (0.099)			-1.195 (3.699)
c ₅					-1.303 (2.961)
$\sum c_i$			-0.074 (0.487)	-4.483	-5.334
R ²	0.979	0.983	0.960	0.845	0.932
D.W.	1.245 ⁽³⁾	1.768	2.396	2.008 ⁽⁴⁾	1.741

Notes: ⁽¹⁾ a=constant term; b=short-run income (activity) elasticity; c₀=short-run price elasticity; c₁, c₂, c₃, c₄=lagged price elasticities; $\sum c_i$ =long-run price elasticity (significant coefficients only); d=weather elasticity.

⁽²⁾ t-ratios in parentheses;

⁽³⁾ The estimates were corrected for serial correlation;

⁽⁴⁾ The Durbin-Watson statistic is reported, although biased towards 2 in the presence of lagged dependent variable, for lack of any more relevant statistic.

of misspecification, the income (activity) variable tends to 'overexplain' the effect of activity level on energy demand.

Aggregate energy

The elasticity estimates clearly depend on the choice of dynamic specification. The Koyck model produces significantly smaller elasticities than the Almon model. Of the two, the Almon model is to be preferred because of its greater precision. The Almon model has a fourth-order linear lag structure. Only the first three lagged coefficients are statistically significant at the 5% level. This is not meant to imply unequivocally that the effects of a price change are exhausted after three years—only that the identifiable, measurable effect dissipates after that period. The effect of a 1% change in price in the current period is to alter energy consumption in the opposite direction by 0.096%

TABLE 4

COAL CONSUMPTION OF HOUSEHOLDS

Estimation period Lag structure	1960-84 Static	1960-84 Almon linear
Total length (in years) of lag distribution Parameter ^{(1), (2)}	0	4
a	4.421 (3.783)	14.848 (3.686)
b	-0.363 (4.552)	-1.341 (3.111)
c ₀	0.482 (2.136)	0.028 (0.176)
c ₁		-0.060 (0.555)
c ₂		-0.148 (1.713)
c ₃		-0.236 (2.179)
c ₄		-0.324 (2.067)
$\sum c_i$		-0.560 (0.807)
d	-0.048 (2.165)	-0.012 (0.885 ⁽³⁾)
R ²	0.730	0.885 ⁽³⁾
D.W.	1.008	(4)

Notes: ⁽¹⁾ a=constant term; b=short-run income elasticity; c₀=short-run price elasticity; c₁, c₂, c₃, c₄=lagged price elasticities; $\sum c_i$ =long-run price elasticity (significant coefficients only); d=weather elasticity;

⁽²⁾ t-ratios in parentheses;

⁽³⁾ Unadjusted for degrees of freedom;

⁽⁴⁾ The estimates were corrected for serial correlation, but unfortunately, the relevant SAS procedure did not generate the corrected D.W. statistic.

This is clearly a rather inelastic response. As expected, the intensity of response becomes stronger (but still inelastic) over the long term when the total effect of a 1% change in price alters the level of consumption by 0.318%. (Observe that the lag structure results because of the nature of the polynomial fit through the coefficients).

How do these elasticities compare with international experience? The statistical evidence suggests that both the short-run and long-run elasticity of demand for aggregate energy are smaller (in absolute value) than those generally obtained for Western economies. (See Table 9). For the industrial sector the price elasticities were estimated by a three-order linear Almon scheme and they are rather small, -0.048 and -0.248, respectively. These are significantly smaller (in absolute value) than those generally obtained for the Western economies. (See Table 10). For the agricultural sector no statistically significant price elasticities could be obtained either by the static or the dynamic specifications. This suggests an almost total lack of price responsiveness with respect to aggregate demand for energy.

TABLE 5

ELECTRICITY CONSUMPTION

Estimation period Lag structure	Industry			Agriculture			Households		
	1960-84 Static	1960-84 Koyck	1960-84 Almon linear	1960-84 Static	1960-80 Almon linear	1960-84 Static	1960-84 Koyck	1960-84 Almon linear	1960-84 Almon linear
Total length (in years) of lag distribution Parameter ^{(1), (2)}	0	∞	3	0	4	0	∞	3	3
a	0.737 (3.545)	0.190 (1.240)	0.461 (1.689)	-3.568 (1.516)	0.615 (0.242)	-0.080 (0.035)	2.059 (6.244)	7.167 (2.600)	7.167 (2.600)
b	0.864 (62.584)	0.745 (10.330)	0.859 (43.931)	4.031 (16.956)	3.193 (11.926)	1.794 (7.553)	0.525 (2.496)	1.053 (3.561)	1.053 (3.561)
c ₀	-0.017 (0.465)	0.006 (0.237)	-0.041 (1.425)	-2.117 (5.536)	-0.807 (3.896)	-0.763 (3.002)	-0.342 (9.616)	-0.380 (2.920)	-0.380 (2.920)
c ₁			-0.005 (0.421)		-0.614 (5.444)			-0.387 (4.690)	-0.387 (4.690)
c ₂			0.031 (1.794)		-0.420 (5.851)			-0.394 (4.805)	-0.394 (4.805)
c ₃			0.066 (1.874)		-0.227 (1.594)			-0.401 (3.108)	-0.401 (3.108)
c ₄					-0.033 (0.139)				
$\sum c_i$					-1.841				
R ²	0.995	0.858	0.997 ⁽³⁾	0.952	0.949	0.983	-1.988	-1.562	-1.562
D.W.	0.565	2.053 ⁽⁴⁾	(3)	1.709	2.169	0.804	2.353 ⁽⁴⁾	0.960 ⁽³⁾	0.960 ⁽³⁾

Notes: ⁽¹⁾ a=constant term; b=short-run (activity) elasticity; c₀=short-run price elasticity; c₁, c₂, c₃, c₄=lagged price elasticities; $\sum c_i$ =long-run price elasticity (significant coefficients only);

⁽²⁾ t-ratios in parentheses;

⁽³⁾ Unadjusted for degrees of freedom;

⁽⁴⁾ The Durbin-Watson statistic is reported, although biased toward 2 in the presence of lagged dependent variable, for lack of any more relevant statistic;

⁽⁵⁾ The estimates were corrected for serial correlation, but, unfortunately, the relevant SAS procedure did not generate the corrected D.W. statistic.

TABLE 6

HEATING OIL CONSUMPTION OF HOUSEHOLDS

Estimation period Lag structure	1970-84 Static	1970-84 Almon linear
Total length (in years) of lag distribution	0	2
Parameter ^{(1), (2)}		
a	-5.706 (1.606)	1.282 (0.914)
b	3.251 (4.895)	1.941 (3.920)
c ₀	-1.101 (2.409)	-0.578 (2.900)
c ₁		-0.355 (3.229)
c ₂		-0.132 (0.587)
$\sum c_i$	-0.206 (0.404)	-0.933
R ²	0.801 ⁽³⁾	0.558
D.W.	1.733 ⁽⁴⁾	1.880

Notes: ⁽¹⁾ a=constant term; b=short-run income elasticity; c₀=short-run price elasticity; c₁, c₂=lagged price elasticities; $\sum c_i$ =long-run price elasticity (significant coefficients only);

⁽²⁾ t-ratios in parentheses;

⁽³⁾ Unadjusted for degrees of freedom;

⁽⁴⁾ The estimates were corrected for serial correlation.

TABLE 7

PETROL CONSUMPTION OF HOUSEHOLDS

Estimation period Lag structure	1960-84 Static	1960-84 Koyck	1970-84 Koyck	1960-84 Almon linear
Total length (in years) of lag distribution	0	∞	∞	3
Parameter ^{(1), (2)}				
a	-9.288 (16.909)	-2.910 (10.980)	-5.706 (5.302)	-9.341 (11.909)
b	3.006 (20.818)	2.743 (13.708)	3.454 (7.160)	2.943 (14.777)
c ₀	-0.092 (1.178)	0.062 (1.420)	-0.005 (0.078)	-0.067 (0.761)
c ₁				0.002 (0.046)
c ₂				0.071 (1.696)
c ₃				0.139 (1.538)
R ²	0.995 ⁽³⁾	0.946	0.908	0.993 (5)
D.W.	1.233	1.308 ⁽⁴⁾	1.631 ⁽⁴⁾	

Notes: ⁽¹⁾ a=constant term; b=short-run income elasticity; c₁, c₂, c₃=lagged price elasticities;

⁽²⁾ t-ratios in parentheses;

⁽³⁾ The Durbin-Watson statistic is reported, although biased toward 2 in the presence of lagged dependent variable, for lack of any more relevant statistic.

⁽⁴⁾ The estimates were corrected for serial correlation, but, unfortunately, the relevant SAS procedure did not generate the corrected D.W. statistic.

TABLE 8

SHORT-RUN AND LONG-RUN PRICE ELASTICITIES

	Short-run	Long-run
Aggregate energy		
Whole economy		
Static model	-0.092	
Koyck model	-0.049	-0.160
Almon model	-0.096	-0.318
Industry		
Almon	-0.048	-0.248
Agriculture		
Static	n.s.	
Oil		
Industry		
Static model	-0.211	
Koyck model	-0.052	-0.277
Almon model	-0.083	-0.321
Natural gas		
Industry		
Static model	n.s.	
Almon model	i.e.	
Households		
Static model	n.s.	
Koyck model	-2.237	-4.483
Almon model	-0.767	-5.334
Coal		
Households		
Static model	i.e.	
Almon model	n.s.	n.s.
Electricity		
Industry		
Static model	n.s.	
Koyck model	n.s.	n.s.
Almon model	n.s.	n.s.
Agriculture		
Static model	-2.117	
Almon model	-0.807	-1.841
Households		
Static model	-0.763	
Koyck model	-0.342	-1.988
Almon model	-0.380	-1.562
Heating oil		
Households		
Static model	-1.101	
Almon model	-0.578	-0.933
Petrol		
Households		
Static model	n.s.	
Koyck model	n.s.	n.s.
Almon model	n.s.	n.s.

Notes: n.s.=statistically not significant at the 5% level (one-tail test).

i.e.=inconsistent estimate (it is statistically significant, but the parameter has the wrong sign).

TABLE 9

SHORT-RUN AND LONG-RUN PRICE ELASTICITIES OF DEMAND FOR AGGREGATE ENERGY IN THE OECD AREA AND SELECTED WESTERN COUNTRIES

	Short-run	Long-run
Author: Prosser (1985); Data: Final energy demand		
OECD countries (1960-82) ⁽¹⁾	-0.26	-0.41
OECD countries (1960-82) ⁽²⁾	-0.22	-0.40
OECD countries (1971-82) ⁽²⁾	-0.26	-0.37
Author: Kouris (1983); Data: Primary energy		
OECD countries (1961-81) ⁽²⁾	-0.147	-0.429
OECD countries (1969-81) ⁽²⁾	-0.162	-0.450
Author: Kouris (1983a); Data: Final energy demand		
Canada (1960-78) ⁽²⁾	-0.15	-0.41
United States (1960-78) ⁽²⁾	-0.16	-0.47
Japan (1960-78) ⁽²⁾	-1.13	-0.47
France (1960-78) ⁽²⁾	-0.14	-0.39
West Germany (1960-78) ⁽²⁾	-0.18	-0.51
Italy (1960-78) ⁽²⁾	-0.11	-0.34
United Kingdom (1960-78) ⁽²⁾	-0.18	-0.41
Our estimate; Data: Direct energy demand		
Hungary (1970-84) ⁽²⁾	-0.049	-0.160
Hungary (1970-84) ⁽¹⁾	-0.096	-0.318

Notes: ⁽¹⁾ An Almon distributed lag hypothesis was assumed.

⁽²⁾ A Koyck distributed lag scheme was assumed to derive the long-term price reaction.

TABLE 10

SHORT-RUN AND LONG-RUN PRICE ELASTICITIES OF INDUSTRIAL DEMAND FOR AGGREGATE ENERGY IN SELECTED WESTERN COUNTRIES

	Short-run	Long-run
Author: IEA/OECD (1982); Period: 1960-79; Data: Final Energy Demand		
Canada	-0.15	-0.38
United States	-0.15	-0.36
Japan	-0.19	-0.48
France	-0.18	-0.39
West Germany	-0.19	-0.45
Italy	-0.14	-0.40
United Kingdom	-0.18	-0.40
Hungary	-0.048	-0.248

Note. A Koyck distributed lag scheme was assumed for the Western countries to derive the long-term price reaction.

Oil

The dynamic models produce reasonably close price elasticities. Clearly both the short-term and the long-term elasticity of industrial demand for oil are inelastic. Even if one accepts the higher estimate for the long-term elasticity,

THE PRICE SENSITIVITY OF THE ECONOMY

the aggregate effect of a 1% change in price is to alter the quantity demanded in the opposite direction by only 0.321% over a period of four years. Again both the short-run and the long-run elasticities are considerably smaller (in absolute value) than those usually obtained for the industrial market economies.⁶

Natural gas

For the industrial sector no significant price reaction could be estimated. In the United States short-run industrial demand has a short-run elasticity in the range of -0.07 to -0.21 and a long-run elasticity in the range of -0.45 to -1.5.⁷ In sharp contrast to industry, the Hungarian household sector's gas demand seems to be fairly responsive to price changes both in the short run and in the long run. Both dynamic models produce reasonably close long-term price elasticities, but they seem to be surprisingly high compared with estimates generally obtained for Western countries.⁸

Coal

No significant price reaction could be estimated for either sector. In the West short-run price elasticity of industrial demand for coal is in the range of -0.10 to -0.49 and the long-run price elasticity ranges from -0.49 to -2.07.

Electricity

No significant price elasticities could be obtained for the industrial sector. Most of the Western studies reveal relatively low short-run price reaction (in the range of -0.10 to -0.20) and a relatively stronger one in the long run (in the range of -0.50 and -1.00).¹⁰

For the agricultural sector a relatively high (in absolute value) short-run and quite a high long-term elasticity are derived by using a fourth-degree linear Almon lag structure. For the household sector the two dynamic models generate relatively similar estimates. These elasticities are close to the upper end of the elasticity values for the Western countries.¹¹

Heating oil

A second-order Almon model (with poor overall exploratory power) yields relatively high elasticity value for both the short run and the long run. These values are quite comparable with estimates obtained for industrial market economies.

Petrol

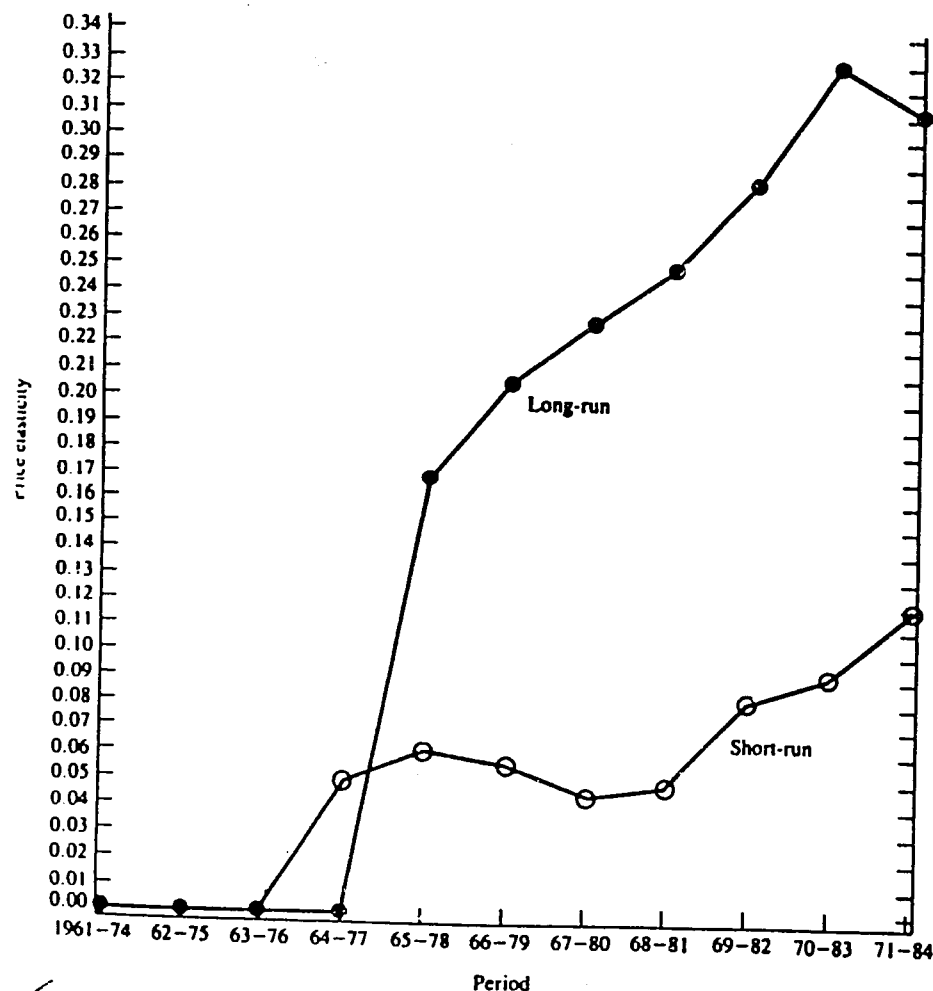
No significant short-term or long-term price reaction could be estimated. The consumer demand for petrol seems to be strongly price-inelastic. The Western literature on petrol demand is rather consistent in concluding that the price elasticity is near -0.2 in the short run and is in the range of -0.4 to -0.8 in the longer term.¹²

The stability of elasticities over time

Of major concern in the context of drawing meaningful inferences over the historical period as well as any forecast horizon is whether the observed relationship (price elasticities) are stable. Stability is defined in the statistical sense that the estimated coefficients of the explanatory variables remain constant over time. This implies that elasticities may vary depending on the period chosen for estimation. A way of investigating the time variation of a regression coefficient is to fit the regression on a short segment of n successive observations and to move this segment along the series.

To estimate variability of elasticities over time the Almon model of the industrial demand for oil (Table 2) was computed for 10 over-lapping 13-year periods. The estimation results are shown in Figure 2. There is clear evidence

FIGURE 2 PRICE ELASTICITY OF INDUSTRIAL OIL DEMAND

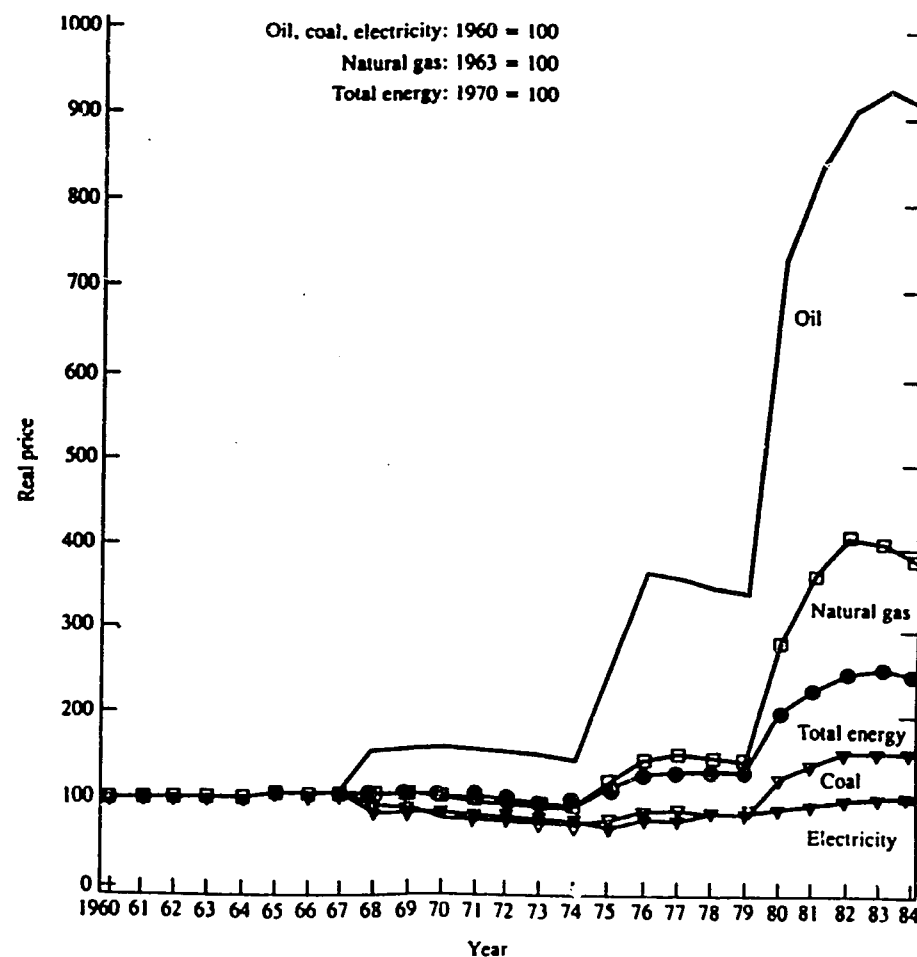


THE PRICE SENSITIVITY OF THE ECONOMY

of an upward trend in both the short-run and the long-run elasticity of industrial demand for oil. Before the mid-1970s no significant price reaction can be estimated, which makes sense since during that period any price variations were minimal. Significant and increasing (in absolute value) price elasticities are associated with a steeply rising trend in the real price of oil (see Figure 3).

It is quite plausible that the increasing trend in the elasticities (i.e., a progressively higher speed of consumer reaction) is some non-linear function of both the level and the rate of change of oil prices. It is likely that consumer responses to real price increases may not occur until a threshold level of real price has been crossed. As the level of real price becomes progressively higher a larger and larger percentage of the consumers' income will be spent on oil, which will leave them less with which to pay for other inputs, with a

FIGURE 3 REAL PRICE OF VARIOUS ENERGY SOURCES



dampening effect on output. Thus the strength of the incentive to reduce oil consumption is proportional to the level of real prices. It is also plausible that the observed time profile of oil elasticities is related to the intensity of the price shock in such a way that the disruptive effects of successive price shocks make oil conservation more imperative than under an alternative situation when price changes follow a more gradual pattern and their effects can be more easily absorbed. We can conclude that there is no such thing as a 'true' elasticity. The fact is that whatever elasticity value exists at one point in time would almost certainly change, at least by a little, at a different point in time.¹³

Some factors behind the low price responsiveness in the Hungarian productive sector

Our empirical results show that, with the partial exception of households, the price elasticity of the demand for energy in Hungary is very small. The elasticity values tend to be unfavourable in international comparison. As suggested earlier, a low price elasticity implies weak reactions to rising energy costs and a protracted adverse effect on output and inflation. In these circumstances increases in energy prices are translated into an increase in the cost of output—an increase in cost nearly as large as the percentage increase in the price of energy multiplied by energy's share in the total cost of output.¹⁴ The higher cost of energy will mean, *ceteris paribus*, a lower real national income, which in turn means lower real wages, profits, investment and consumption levels.

The particularly low short-run elasticity compared with the long-run elasticity implies that the Hungarian economy's short-run vulnerability with respect to the real price of energy is very high. To judge the degree of direct effect on economic growth of change in the real price of energy we estimated a variant of the Cobb-Douglas production function which explicitly includes the real price of energy.¹⁵ It is found that in the period 1960–84 the elasticity of industrial productivity with respect to the real price of energy is -0.142 , meaning that, *ceteris paribus*, a 1% increase in the real price of energy reduces productivity by 0.142%.

Looking over a longer term, however, the reaction of the Hungarian economy to rising energy prices is somewhat better, although still sub-standard relative to the industrial market economies. Several factors might be responsible for this situation.

(i) *Substitution difficulties* between energy and other factors of production such as labour and capital. Generally when energy is considered as a factor of production alongside capital and labour, the answer to whether or not energy availability can become a constraint on economic growth depends on the extent to which it is possible to substitute other factors of production for energy. The econometric evidence for the Western economies demonstrates strong long-run substitution possibilities between labour and energy. Although long-run energy-capital substitutability is a subject of controversy, most studies support the view that short-run energy-capital complementarity is

replaced by substitutability over the long term.¹⁶ Unfortunately no empirical study is available for the Hungarian economy on substitution of non-energy factors for energy. Such work is planned by this author. Until we obtain reliable estimates on interfactor substitution we can only hypothesise that the relatively low Hungarian price elasticity values are related to difficulties in substituting non-energy inputs for energy even over the long run. For example, some substitution between labour and energy is possible but difficult because labour in Hungary has become an increasingly scarce factor input.¹⁷ Capital-energy substitution can be limited even when relative factor prices shift in favour of capital, if energy conservation equipment is not available or of low quality. The general slowdown in investment activity in the recent period has probably impeded the substitution possibilities between capital and energy. It is likely that a better housekeeping approach rather than inter-factor substitution has been the dominant source of whatever amount of energy conservation has been achieved.

(ii) The empirical evidence suggests that Hungarian enterprises have not yet been given sufficient incentive to minimise cost. Even world parity scarcity prices may be insufficient to induce large scale conservation in the productive sector if other components of the economic mechanism (subsidies, taxes, credits, etc.) partly or totally neutralise or diminish their effects. The general softness of enterprise budget constraints is a powerful factor behind the price-inelastic response. Kornai and Matits claim, on the basis of a large scale empirical survey, that there are no visible signs of enterprise budget constraints becoming harder since the 1968 reform.¹⁸

Summary and conclusions

In this chapter we estimated a series of energy demand models for various energy products and consuming sectors. We argue that static models are inappropriate and generally yield biased estimates because they do not capture the dynamic nature of energy demand. This is confirmed by our empirical results. We applied two dynamic models, the autoregressive Koy scheme and the Almon polynomial lag scheme, to estimate short-run and long-run price elasticities of energy demand. The elasticity estimates should be treated with caution. It is not appropriate to interpret price elasticity estimates without giving consideration to the type of estimation model employed, the other variables which bear upon energy consumption, the level of aggregation and the characteristics of the data.

Our empirical estimation shows some evidence of responsiveness in the Hungarian economy to changes in the domestic prices of energy sources. However, with the partial exception of the residential sector, the demand response was found to be rather price-inelastic. In international comparison the Hungarian economy's price sensitivity is probably stronger than that of the traditional centrally planned economies (although no comparable data are available to prove this), but it is significantly weaker than that of industrial market economies. This is in line with the position of Hungary as an intermediate economy in comparative systems terms.

Significant differences exist between the short-run and long-run response intensity. It is found that the effect of a price change works through energy demand over a period of time. This suggests that although in the short run there is very little flexibility to decrease the use of energy in the non-residential sectors, the flexibility becomes somewhat greater (though demand remains inelastic) in the long run as a result of inter-factor substitution, capital stock turnover and other processes.

A stability test was run to estimate the variability of elasticities over time using industrial demand for oil as a case study. It is found that there are important trends in the elasticities themselves; both the short-term and the long-term elasticity follow an upward trend over time. It is suggested that this trend may be some function of both the level and the rate of change of oil prices.

The relatively low price elasticity of energy demand implies weak consumer responses to higher energy costs and a protracted adverse effect on output, inflation, the balance of payments and other macroeconomic variables. Increases in energy prices are being translated into an increase in the cost of industrial output and potentially into a reduction of cost competitiveness in international markets. The low price elasticities also limit the feasibility of dampening energy demand through price-induced effects. This last fact calls for active supplementary use of non-price instruments to encourage conservation.

Two major factors are suggested to account for a good part of the relatively price-inelastic response: (1) substitution difficulties between energy and other factors of production such as labour and capital; and (2) the continuing lack of strong managerial incentives to minimise cost.

Notes

- ¹ See Kouris, 'Energy Demand . . .', p. 73.
- ² For a comprehensive discussion of the estimation problems of energy price elasticities, see, *inter alia*, Bohi, pp. 1-53.
- ³ See Dobozi, p. 205 and Bohi, p. 15.
- ⁴ Kouris, 'Energy Demand . . .', p. 81.
- ⁵ See, *inter alia*, Johnston, pp. 343-381.
- ⁶ For various estimates for Western countries, see Pindyck, pp. 222-4.
- ⁷ See Bohi, p. 159.
- ⁸ It is not unusual to find long-term price elasticity of residential demand for natural gas in Western countries amounting to 2 or more (in absolute terms). See Bohi, p. 94; Pindyck, p. 160.
- ⁹ Bohi, p. 159.
- ¹⁰ For a review of Western estimates, see Bohi, p. 159.
- ¹¹ For a comparison, see Bohi, pp. 57-59; Pindyck, pp. 162-3 and Nemetz and Hankey, pp. 250-251.
- ¹² For a review of Western estimates, see Bohi, p. 130.
- ¹³ For a similar conclusion in the context of the OECD countries, see Kouris, 'Elasticities . . .', p. 68.
- ¹⁴ Pindyck, p. 11.
- ¹⁵ The reduced form equation of the industrial production function is the following:

$$\log(Y/L)_t = 1.320 + 0.869 \log(K/L)_t - 0.142 \log(P_e/P)_t \\ (11.115) (15.942) \quad (3.685)$$

$$\hat{R}^2 = 0.988 \quad D.W. = 0.862$$

where Y = real gross industrial production;
L = labour input (man-hours);
K = real gross capital stock;
P_e = nominal price of energy;
P = industrial producer price.

Note the low D.W. value indicating positive serial correlation in the model. The attempts to remove it were unsuccessful due to lack of convergence. A similar model was estimated by Suzuki and Takenaka (1981, pp. 237-238) for Japanese industry (with a real energy price coefficient -0.1194 for the period 1965-78) and for American industry (-0.1062 for the period 1960-78).
¹⁶ See, *inter alia*, Suzuki and Takenaka, p. 235; Gregory and Griffin, pp. 845-857. For a review of elasticity of substitution estimates with respect to energy and capital, see World Bank, pp. 60-194.

¹⁷ A similar conclusion is drawn by Hewett, p. 131, in the context of the Soviet economy; '... Soviet conservation options are somewhat more limited than they were in the West, where the increased relative price of energy induced enterprises to substitute labour for energy. In the Soviet Union the price of labour will fall relative to energy, but that will only increase the excess demand for labour'.

¹⁸ Kornai and Matits, p. 28.

Statistical Note

Data on direct energy consumption were obtained from Állami Energetikai és Energiabiztonságtudományi Felügyelet. Other data were derived from various issues of *Statistikai Évkönyv* or through personal communication from the Hungarian Statistical Office. Kálmán Dezséri provided valuable help in collecting the data.

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ENERGY AND TRANSPORTATION IN THE UNITED STATES

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INTRODUCTION

Transportation activities accounted for 28% of all US energy use in 1987, or 21.3 quadrillion Btu (quads). More than 97% of this energy was in petroleum products. Moreover, 63% of all petroleum is used directly for transportation, and much of the petroleum used in other sectors is in the form of by-products of gasoline, diesel fuel, and jet fuel production. In addition, while energy use for transportation grew at the relatively moderate average rate of 1.2% per year in 1972-1987, all other sectors slashed their use of petroleum, so transportation's share is larger than in the past (1).

What is the story behind these numbers? The past 15 years have been tumultuous. The oil embargo of the fall of 1973 led to shortages and price controls. The Motor Vehicle Information & Cost Savings Act of 1975 introduced the Corporate Average Fuel Economy standards. The second oil shock, accompanying the Iranian revolution of 1979, led to long lines at filling stations and high fuel prices. Then, as governments, equipment manufacturers, and consumers around the world moved toward more efficient use of petroleum, and oil producers moved to increase production, oil prices fell and fuel again became plentiful. The typical price of gasoline in the United States is now about the same as in 1972, after accounting for the general inflation.

But we have hardly returned to 1972 conditions. Our capital, human knowledge, institutions, and equipment have changed forever. Our un-

derstanding of transportation energy issues—supplies of petroleum, the efficiency of its use, the side effects of its extraction and use, and even alternatives to the present energy-using system—is far deeper today than before the adventures of the past 15 years.

In this paper, energy use in all areas of transportation is briefly analyzed. Then a coherent subset of issues facing the largest of the activities, personal passenger transportation based on petroleum fuels, is explored in depth: the reasons for past and future growth in driving, the past developments in fuel economy, and the possibilities for change in the next one to two decades. This look ahead involves (a) the technical potential for further improvement in fuel economy and reductions in air pollution, (b) the role of the market in these areas, and (c) the role of public policies.

This narrow focus has been adopted to enable the exploration of several perspectives on one area of transportation in some depth. Other fuel options and other transportation modes are of course important, and are very briefly discussed at the end of this paper. Nevertheless, petroleum-fueled personal passenger transportation is the largest energy user, accounting for 58% of transportation energy use, and will remain so for the period in question. Although there are alternatives of considerable interest, there will be no rush to embrace them on a national scale.

ACTIVITY AND ENERGY USE, 1972–1985

In this section, energy use in 1985 is first disaggregated. In each subsector, energy use is expressed as the product of a level of activity and an energy-intensity. For example, for automobiles the activity selected is vehicle-miles traveled and the energy-intensity is then expressed in Btu per mile. Total energy use is a sum of such products:

$$E = \sum_i A_i(EI)_i$$

1.

Using the simple but elegant Divisia technique, the change in energy use over time is then decomposed into a change due to changed activity levels and a change due to changed energy-intensities.

Transportation in 1985

There are several sources of data on energy and activity in transportation; this richness of data makes the sector more congenial for the energy analyst than any other sector except manufacturing. Using these sources, a group at Oak Ridge National Laboratory has disaggregated transportation energy use (Table 1.10 of Refs. 2 and 3).

One area of transportation that needs a more ambitious disaggregation is

trucks. The light truck has been the most rapidly growing category of transportation, more so than air travel. It is, however, primarily a categorization problem. Trucking is dominated in fuel use by light trucks (pickups, vans, and jeep-like vehicles, under five tons); about three fourths of light trucks, in turn, are now being used as cars (4). A good analysis requires disaggregation of trucking into light trucks used as personal passenger vehicles, light trucks used for freight, 5–13-ton trucks, and very heavy trucks. (In the tables in this article the last two are grouped together as heavy trucks.) Among the reasons for the shift to pickup trucks as passenger vehicles is the decreasing number of passengers in typical trips. The average household size declined from 3.14 in 1970 to 2.66 in 1987, and the average occupancy of automobiles declined from 2.2 to 1.5 or 1.6. Light trucks also appear to be more durable than cars. The average light truck is scrapped after 14 years, while the average car is scrapped after 10 (Table 2.11 of Refs. 2 and 3). Other advantages of light trucks may flow from the fact that they are more lightly regulated with respect to fuel economy, emissions, and safety than cars.

Two sources of first-hand data permit the disaggregation of trucking: the Census's Truck Inventory and Use Survey (TIUS) of 1982 (4) and the 1985 Residential Transportation Energy Consumption Survey (RTECS) of the Energy Information Administration (EIA) (5). The activities and energy use of highway vehicles are obtained from these sources (Table 1). In preparing this table, an inclusive definition of light trucks, as to types of vehicle, is used. In some other studies, light trucks comprise a more restricted group of vehicles. This difference largely explains the larger activity and energy use by light trucks (and smaller by heavy trucks) in Table 1, compared to the results of some other studies (2, 8, 9, 10).

Table 2 shows energy, activity, and energy-intensity in detail for all of transportation in 1985. The main characteristic is the dominance of personal passenger vehicles. Passenger transportation dominates freight in energy use, and personal vehicles dominate passenger transportation. Personal passenger vehicles account for 58% of all transportation energy use and for 85% of all passenger-miles (assuming a personal vehicle occupancy of 1.6 in 1985). Commercial air carriers provide 11% of the passenger-miles, while buses and trains together provide only 4%.

The personal vehicle is more energy intensive than the other forms of passenger transportation, but not by as much as many think. The average car is shown in Table 2 to have an energy-intensity of 7100 Btu per mile (an in-use fuel economy of 17.6 mpg). An urban transit bus has an energy-intensity of 3600 Btu per passenger-mile (Table 2, note e). So a car with two people, or a car with one person but twice the average fuel economy, not only goes where and when you want, but has roughly the same energy-intensity per passenger-mile as an urban bus. (The low energy-intensity for buses in Table

Table 1 Highway vehicle activity and energy use, 1985

	Vehicles ^a (millions)	Miles/vehicle (thousands)	Vehicle-miles ^b (trillions)	mpg	Energy (quads)
Automobiles					
household	104	9.7 ^c	1.01	17.2 ^d	7.35
fleet	10.5 ^e	27	0.28	20 ^f	1.78
passenger light trucks ^g	28.7 ^h	9.6 ^c	0.28	13.3 ^d	2.60
freight light trucks ⁱ	9.6 ^h	10.5 ^j	0.10	12 ^j	1.05
heavy trucks ^k	4.1	23	0.035	5.4	2.40
buses ^l	0.6	10	0.006		0.15
motorcycles			0.009		0.02
Total			1.78		15.35 ^m

^aAutomobile and truck totals based on R. H. Polk data (pp. 28, 29 of Ref. 6)

^bIn approximate accord with data from the Department of Transportation (7), (p. 53 of Ref. 6)

^cFrom (5), but slightly less to account for some of those vehicles used by households being fleet automobiles or freight light trucks with higher use.

^d(5)

^e(Table 2.35 of Refs. 2 and 3)

^fEstimate between new-car in-use fuel economy of 22 mpg and household fuel economy of 17 mpg.

^gIncludes pickups, vans, and jeep-like vehicles.

^hFor number of light trucks, subtract heavy trucks from total. Assume 75% of light trucks are used for personal passenger transportation. This assumption is based, for example, on 1982 TTUS results that 73% of light trucks do not carry freight (4). (Freight includes craftsman's tools.)

ⁱUnder 10,000 lbs.

^jMiles per vehicle adjusted is up about 10% and fuel economy down about 10% from household trucks (5).

^kBased primarily on summary of TTUS (Table 2.39 of Refs. 2 and 3). Number of heavy trucks based on 3.58 million in 1982 (TTUS), addition of 5.4 million trucks in 1982-1985, and sales fraction of heavy trucks of 9% in the period (pp. 10, 11 of Ref. 6). 1985 miles per vehicle, vehicle-miles, and fuel economy generated assuming (a) that miles per vehicle-year of trucks over 26,000 lb. remained at 36.6 thousand, and those of trucks between 10,000 and 26,000 lb. remained at 9.5 thousand (TTUS), and (b) that 1982 fuel economies improved 2%. The results of this exercise for 1985 is 76 and 19 million vehicle-miles, and 27.5 and 19.1 thousand Btu per mile, for the heavier and less heavy groups of trucks, respectively. The resulting energy use is: diesel 1.95 and 0.08, gasoline 0.10 and 0.27 for the two groups of heavy trucks, respectively, in quads (quadrillion Btu).

^lTables 2.47 and 2.48 of Refs. 2 and 3

^mThis quantity (and gasoline and diesel totals) was used as a control total to make minor adjustments.

2 is due to school buses and the shaky assumption that their average passenger load is 20. The average load of the urban transit bus is 17.) The energy-intensity of certificated air carriers is also not as great as one might, at first, think.

Freight energy use is also dominated by highway vehicles, but freight activity measured in ton-miles is dominated by nonhighway modes. The nonhighway freight modes are much less energy intensive than heavy trucks. Note that gas pipelines are fairly energy intensive, however; a gas is much more difficult to pump than a liquid.

The Change from 1972 to 1985

Many of the transportation activities have been tracked in consistent or nearly consistent data series since 1970 and before. For this paper, the period

Table 2 Transportation activity and energy use, 1985^a

Mode	Energy (quads)	Activity ^b unit	Activity (trillions)	Energy-intensity (thousand Btu per unit)
Passenger				
automobiles ^c	9.16	VM	1.29	7.1
light trucks ^d	2.60	VM	0.28	9.3
buses	0.15	PM	0.11 ^e	1.4 ^e
rail	0.05 ^f	PM	0.015	3.5 ^f
air	1.61 ^g	PM	0.336	5.0 ^g
subtotal	13.57			
Freight				
light trucks ^d	1.05	VM	0.10	10.4
heavy trucks	2.40	TM	0.7	3.4
rail ^h	0.45	TM	0.91	0.49
marine ⁱ —domestic	0.30	TM	0.89	0.34
—foreign	0.75	lbs	1.54	0.5
pipelines ^j	0.55 ^f	TM	0.26	2.1 ^f
subtotal	5.50			
Miscellaneous				
military	0.70			
recreational boats	0.22			
general aviation	0.14			
subtotal	1.06			
Grand total	20.12			

^aAdapted from Table 1.10 (Refs. 2, 3) and Table 1.

^bPM, passenger-miles; VM, vehicle-miles; lbs, pounds shipped; TM, ton-miles.

^cIncludes motorcycles

^dUnder 10,000 lbs.

^eAssumes occupancy of 20 passengers in school buses. The energy-intensity of urban transit buses is stated to be 3.6 thousand Btu/PM.

^fIncludes losses in generating and distributing electricity.

^gFreight-activity, responsible perhaps for 0.05 quad, is included. Energy use is purchases of domestic fuel by domestic and international carriers. The energy-intensity is based on total fuel used, roughly corrected for freight activities.

^hTable 3.9 of Refs. 2 and 3.

ⁱTables 3.5 and 3.6 of Refs. 2 and 3.

^jNatural gas pipelines only. Activity is based on total consumption of natural gas (1) and assumed average transportation of 620 miles.

1972-1985 is selected for an analysis of trends. Energy consumption in 1972 and 1985, and average growth rates for activity during that period, are shown in Table 3. (It will be seen that our analysis does not require activities in different subsectors to be measured in the same units. Energy use measures must be commensurate across subsectors, however.)

Table 3 reveals the critical role of the light truck as a personal passenger vehicle. It also shows the growing importance of air travel, as well as the relatively slow growth of most freight activities. In the latter connection,

Table 3 Transportation energy use and activity, 1972-1985

	Energy (quads)		Activity means ^a	Growth rates (percent per year)	
	1972	1985		activity	energy-intensity ^b
Passenger					
automobiles	9.18 ^c	9.16	VM	2.1 ^d	-2.1 ^e
light trucks ^f	1.11	2.60	VM	8.9	-2.0
(combined)	(10.29)	(11.76)	VM	3.0	-2.0
buses ^g	.11	0.15	PM	2	1
rail ^h	.04	0.05	PM	0.3	1
air ⁱ	1.30	1.61	PM	6.3	-4.6
subtotal	11.74	13.57			
Freight					
light trucks ^j	0.99	1.05	VM	1.9	-1.4
heavy trucks ^k	1.82	2.40	GNP ^l	2.5	-0.3
rail ^m	0.57	0.45	TM	0.9	-2.7
marine ⁿ —domestic	0.32	0.30	TM	2.9	-3
—foreign	0.69	0.75	T	1.6	-1
pipelines ^o	0.77	0.55	quads	-1.7	-1
subtotal	5.15	5.50			
Total ^p	16.90	19.07			

^a VM, Vehicle-miles; PM, passenger-miles; TM, ton-miles; T, tons shipped; quads, quadrillion Btu (of natural gas consumed in the United States).

^b Independent data for cars and to a lesser extent for light trucks, but energy-intensity trends are typically calculated as difference in growth rate between energy and activity.

^c Table 1.13 of Refs. 2 and 3.

^d Automobiles (excluding motorcycles) were driven 986 and 1290 billion miles in 1972 and 1985, respectively (7).

^e Consistent with change from 13.5 to 17.8 mpg.

^f The light truck VM in 1972 is the difference between total truck VM (7) and non-light-truck VM (Table 2 of Ref. 11). Thus it equals 260 - 90 = 170 billion. The fraction of these vehicles used as passenger vehicles in 1972 (0.534 from Ref. 11) is used to apportion the VM, yielding 91 billion VM for passenger light trucks. Fuel used is determined assuming that fuel economy improved 2% per year in 1972-1985, so fuel use for passenger light trucks in 1972 = (91/275) exp(13 × ln 1.02) × 2.60 = 1.11 quads, where 275 billion VM were traveled in 1985.

^g (Tables 2.45 and 1.18 of Refs. 2 and 3). The average occupancy of school buses is assumed to be 20.

^h Tables 3.11 and 3.12 of Refs. 2 and 3.

ⁱ Table 3.1 of Refs. 2 and 3, corrected to domestic fuel purchases.

^j Fuel use is based on assumed fuel economy of 10 mpg and VM from note f: (79/10) × 1.25 = 0.99 quads. Activity grows from 79 to 101 billion miles (Table 1).

^k Fuel use for all trucks (Table 1.13 of Refs. 2 and 3) or 3.91 quads in 1972, from which 2.10 for light trucks (notes f and j) is subtracted. Activity is taken proportional to real GNP. An alternative would be ton-miles in intercity motor freight, which grew from 470 to 610 billion from 1972 to 1985 (p. 57 of Ref. 6).

^l Table 3.9 of Refs. 2 and 3.

^m (Tables 3.5 and 3.6 of Refs. 2 and 3). A universal 1% per year energy-intensity reduction is assumed for foreign.

ⁿ Natural gas pipelines only. No historical data is available on energy use for pipelines for petroleum or materials other than natural gas.

^o Miscellaneous uses have been omitted from Table 1.

although value measures of trade and freight are increasing, tonnage measures are declining with respect to GNP. This reflects the growing share of consumption, in advanced industrial societies, accounted for by less materials-intensive, and therefore lighter, products (12).

The data in Table 3 has been set up to enable a Divisia decomposition. Define $G(X)$ to be the compound growth rate, measured in percent per year, of a quantity $X(T)$:

$$G(X) = (100/T) \ln[X(T)/X(0)]$$

with T in years; and define the weighted average growth rate:

The Divisia decomposition of Equation 1 is:

$$G(E) \approx \langle G(A) \rangle + \langle G(E/A) \rangle \quad 2.$$

where one should note

$$\langle G(E/A) \rangle = \langle G(E) \rangle - \langle G(A) \rangle$$

Here W_i is the time-average energy weight of the subsector:

$$W_i = 1/2[E_i(T)/E(T) + E_i(0)/E(0)]$$

[See Boyd et al (12a) for further details.] Equation 2 states that the average growth rate in energy use (approximately) equals the energy-weighted average growth in activity plus the average growth in energy-intensity. (For typical energy-use time series, the approximation is good to about 0.1% per year or better.)

The results of the analysis are summarized in Table 4. The behavior for transportation as a whole is the same as that for personal passenger vehicles alone: growth in activity at an average 3% per year, but a rapid decline in energy-intensity, so that energy use grew only 1% per year in this period.

The separate results for passenger and freight activity show what is not surprising to any observer of the US scene: travel is increasing rapidly, but so is the energy-efficiency with which it is provided. Freight activity in ton-miles has been increasing much less rapidly, a characteristic of an affluent and mature society. At the same time, it has proven more difficult to improve the

Table 4 Divisia analysis of energy used for transportation, 1972-1985

(growth rates in percent per year)			
	Activity	Energy-intensity	Energy
Passenger	3.6	-2.4	1.1
Freight	1.7	-1.1	0.5
Total	3.0	-2.0	1.0

energy-efficiency of freight services. (The notes to Table 3 show that the freight data is much less complete and therefore the decomposition for freight is less reliable than that for passenger travel, but the essential picture is clear.)

If we want to understand these results, we must decompose and probe them further. What is responsible for the growth in travel? What is responsible for the decline in energy-intensity? In the next two sections these questions will be explored with respect to personal passenger vehicles.

TRENDS IN HIGHWAY TRAVEL

Vehicle travel continues to grow in spite of arguments that saturation is imminent. Figure 1 shows total vehicle-miles traveled, and Figure 2 total vehicle-miles per adult (i.e. total vehicle-miles divided by the population aged 16 and over). The data and a curve with adjusted parameters for income and fuel price effects are shown. The theoretical curve is almost proportional to real disposable income per capita, corrected by a moderate fuel price elasticity effect, representing an elasticity of -0.1 (indicating that a 10% increase in the fuel price induces a 1% decline in consumption). In a slightly different approach to these data, Werbos found a fuel price elasticity of -0.2 (14).

The decomposition of this trend in vehicle-miles will be based on information from the 1983 National Personal Transportation Survey (NPTS) on drivers and their driving (15). From our present perspective, however, 1983 was an unusual year because of the high fuel prices, with a real fuel price 42% higher than now, so in the following the amount of driving in that year will be corrected by a factor of $(1.42)^{0.15} = 1.05$ (where the average of the two elasticities mentioned in the last paragraph is adopted). That is, about 5% more driving would have occurred in 1983 had gasoline prices been like those of 1986. This correction crudely represents the effect on vehicle-miles of the fuel price excursion of the late 1970s and early 1980s.

Just because income per person provides a good statistical fit to the general growth trend for driving does not mean it is a good interpretation. De-

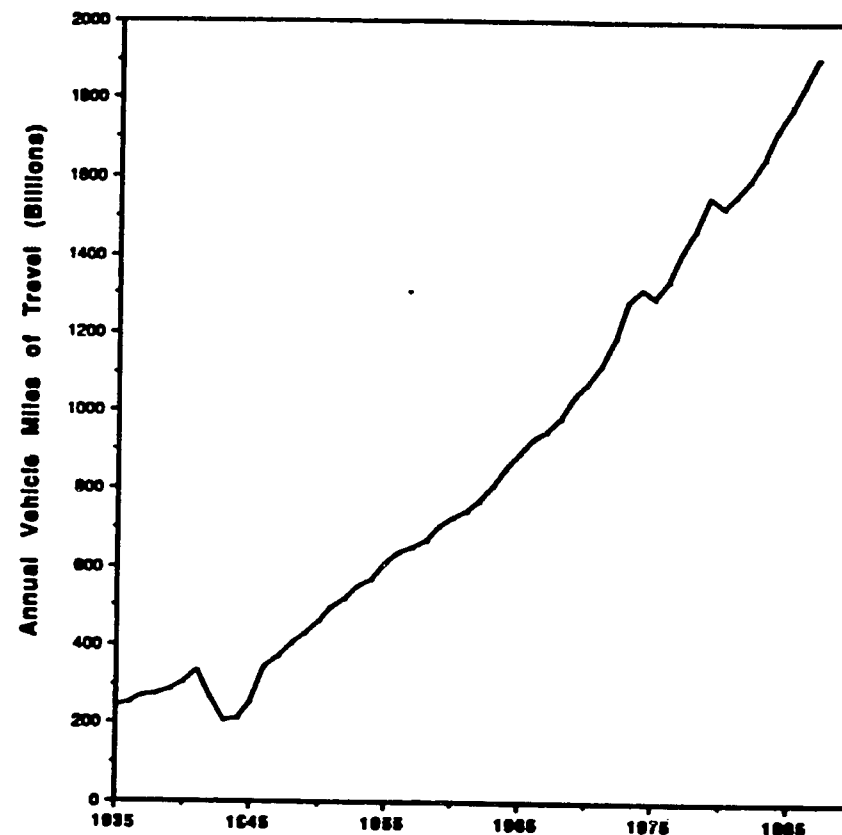


Figure 1 Total vehicle-miles traveled on highways annually (in the 12 months prior to January of the year shown). Source: (13)

mographics provide a more interesting perspective. Much of the growth in driving since the late 1960s is associated with women moving into the labor force and those women becoming drivers (Table 5). In 1969, 39% of adult women were employed; in 1983, 50% were employed. In 1969, 74% of employed women had drivers licenses; in 1983, 91% did. The relative increase in licensed drivers accounts for half the growth in driving per adult shown in Figure 2 between 1969 and 1983.

From 1969 to 1983 (corrected), personal vehicle-miles traveled grew at a rate of 3.5% per annum (p.a.). This growth can be described in terms of the 1.8% p.a. growth rate in number of adults, a growth of 0.6% p.a. due to shifts in employment and the changing role of women discussed in the previous paragraph, and the residual, a 1.1% p.a. growth in driving per licensed driver.

In the next decade growth in the number of adults will slow dramatically, as

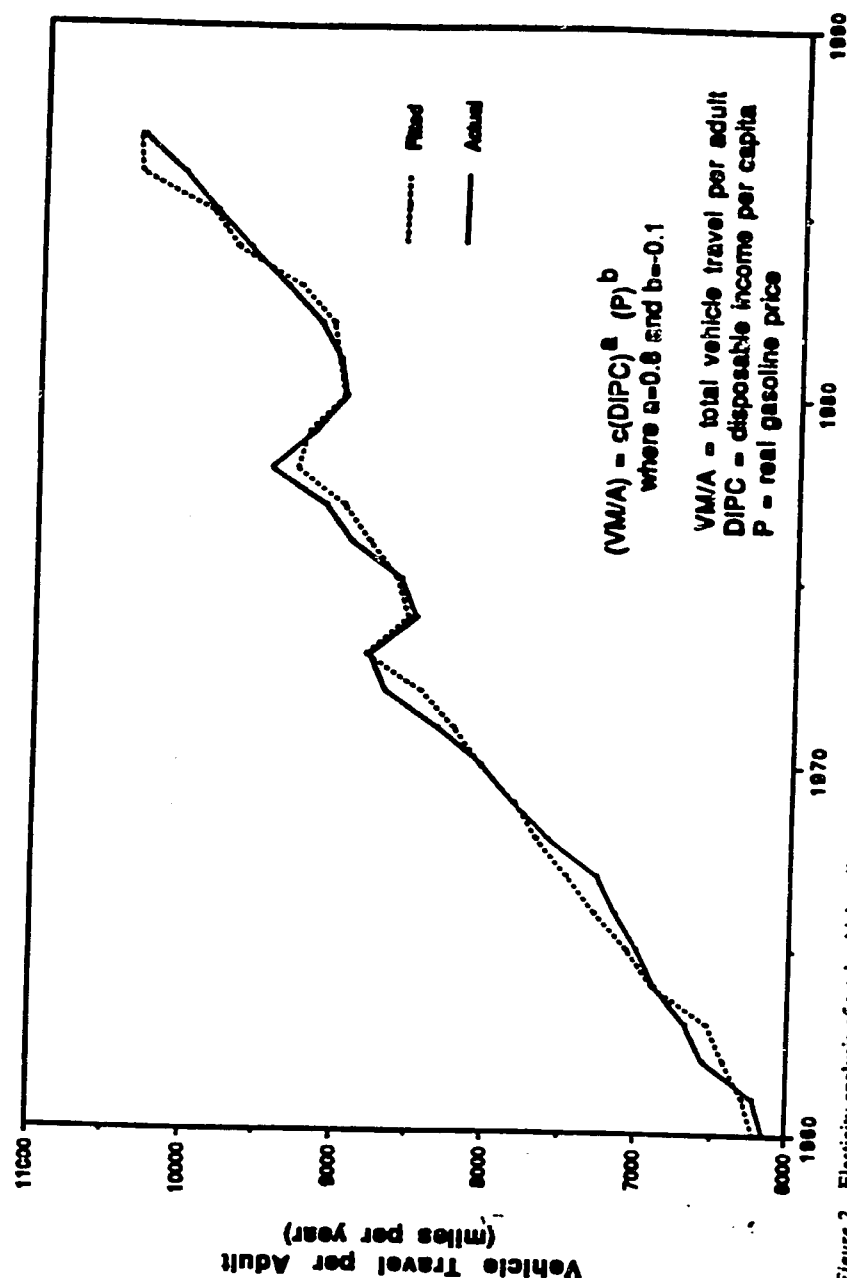


Figure 2 Elasticity analysis of total vehicle-miles traveled per adult. The analysis is similar to that of (14), but differs in details as well as including more recent data. Source of primary data: (13)

Table 5 Drivers licenses and driving, by sex and employment

	1969		1983		Annual miles per driver (1000s)
	% of adults	% with license	% of adults	% with license	
<u>Employed full time</u>					
<u>or part time</u>					
Male	36.3	93.5	34.4	95.8	15.9
Female	20.8	74.1	26.0	91.1	7.7
<u>Not employed</u>					
Male	10.5	64.8	13.2	76.0	7.7
Female	32.4	54.9	26.4	64.2	4.5
Total	100	75.1	100	83.6	10.3

Source: (15)

will the effect of increasing employment and licensing of women (because they have already moved so far toward matching men in this respect). If men and women in 2000 have the employment-licensing characteristics of men in 1983 (in the various age groups) and if the average growth rate of driving per licensed driver remains the same as for 1969-1983, then vehicle-miles traveled will grow an average of 2.4% per year from 1983 to 2000. This slower growth should be felt soon, after the response to the fuel price reductions of the mid-1980s is complete—if the analysis is accurate.

The projection of slower growth in road travel is supported by two other facts. The distance driven per driver is unlikely to increase much further for the predominant cohort, employed men in their prime years (25-54). This group already drives an average of 18,000 miles per year or about 1 1/2 hours per day. Moreover, as shown in Figure 3 for all employed men, this driving pattern is essentially independent of income (unpublished analysis of the NPTS data by Anant Vyas). (In the past, evidence has been offered for a fairly strong income dependence of vehicle-miles per household, but that is of less interest than the weak dependence shown, which is for vehicle-miles per driver.)

On the other hand, there is no hint that the information revolution will reduce the amount of travel. If anything, just as more information seems to lead to more use of paper, better information and communication may lead to increased travel. The cellular phone may, for example, lead some people to spend more time in their vehicles. More important, the growth in part-time work and business services is leading people to spend more time on the road. These developments are abetted by the information revolution, but are also partly due to a relative decline in full-time work with good pay.

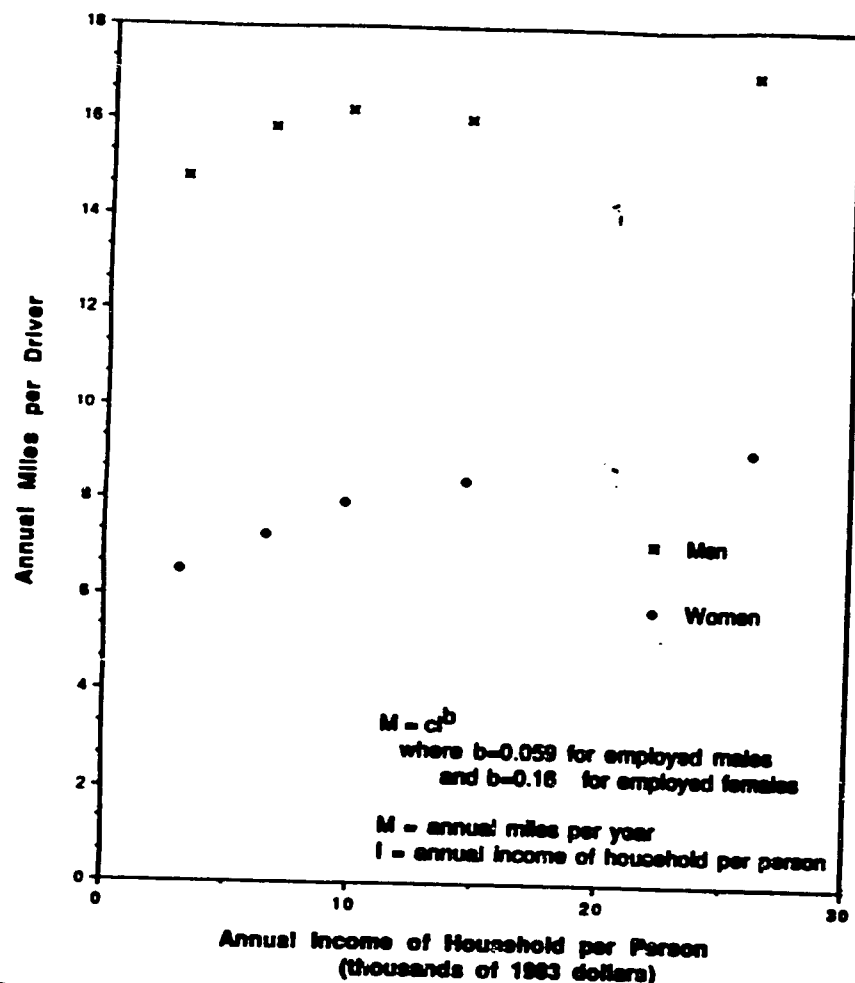


Figure 3 Distance driven per driver (in thousands of miles) vs household income per person, showing the small income elasticity of driving in the United States. Data is for 1983 from (15)

The description of vehicle-miles traveled on the basis of the number of drivers, just presented, is in contrast to one based on the vehicles in use—an approach that has been widely used in forecasting. The trouble with using miles per vehicle for forecasting is that, in the United States, a fundamental shift in the use of private vehicles is now beginning to take place. The number of households with more vehicles than drivers is becoming large. This trend toward extra, probably special-use, vehicles may well continue strongly as vehicles are kept in service longer and the adult population grows more

slowly. (For example, the median age of cars in use has increased two years since the early 1970s.) The growth in the number of vehicles and, especially, their use is thus difficult to forecast accurately.

In conclusion, recent growth in vehicle-miles has been fueled by the baby boom cohort entering adulthood and the changing role of women. Those sources of growth are saturating, so total vehicle-miles should start to grow more slowly. Nevertheless, there is still considerable room for growth in vehicle-miles.

RECENT TRENDS IN FUEL ECONOMY

The Mix of Vehicles Purchased

Since its nadir of about 14 mpg in 1973, the fuel economy of new cars has approximately doubled to 28 mpg. (These new-vehicle fuel economies are nominal, i.e. laboratory measurements. Their relation to in-use fuel economy is discussed below.) The average fuel economy of new light-duty vehicles (both cars and light trucks) has, however, only increased one mpg since 1981 (Figure 4). One important reason for slower growth in fuel economy compared to the previous period is that consumers are switching to light trucks, and their fuel economy is lagging.

The early 1970s saw a shift to smaller cars. In spite of frequent remarks to the contrary, however, consumers are not switching back to larger cars (Figure 5), although they did, to a small extent, in the early 1980s. If the size of cars is specified in terms of interior volume, then one finds that the sales-weighted average volume has hardly changed in the past decade. The Environmental Protection Agency (EPA) interior volume averaged 109 ft³ in 1978, fell to a low of 104 ft³ in 1980, and is now steady at 108 ft³.

In addition, while there is considerable variation in fuel economy within each automobile size class, especially in the small classes, the average fuel economies for each class vary only 30% from the smallest to the largest size class (Figure 6). This is in part due to the low fuel economies of some heavy high-powered cars that are styled as sport cars and so have low interior volume, with the result that the average fuel economy in the smaller classes is held down. In other words, while the very highest-fuel-economy cars are indeed small, buying the average small car does not ensure getting a high fuel economy.

With these observations in mind, it is not surprising that a Divisia analysis of automobiles by size class shows that only one-tenth of the fuel-economy improvement in new cars from 1976 to 1988 was due to consumers' shifting to smaller cars, while the lion's share came from fuel-economy improvements within each size class (Figure 7). This analysis is, however, somewhat sensitive to how the size classes are defined.

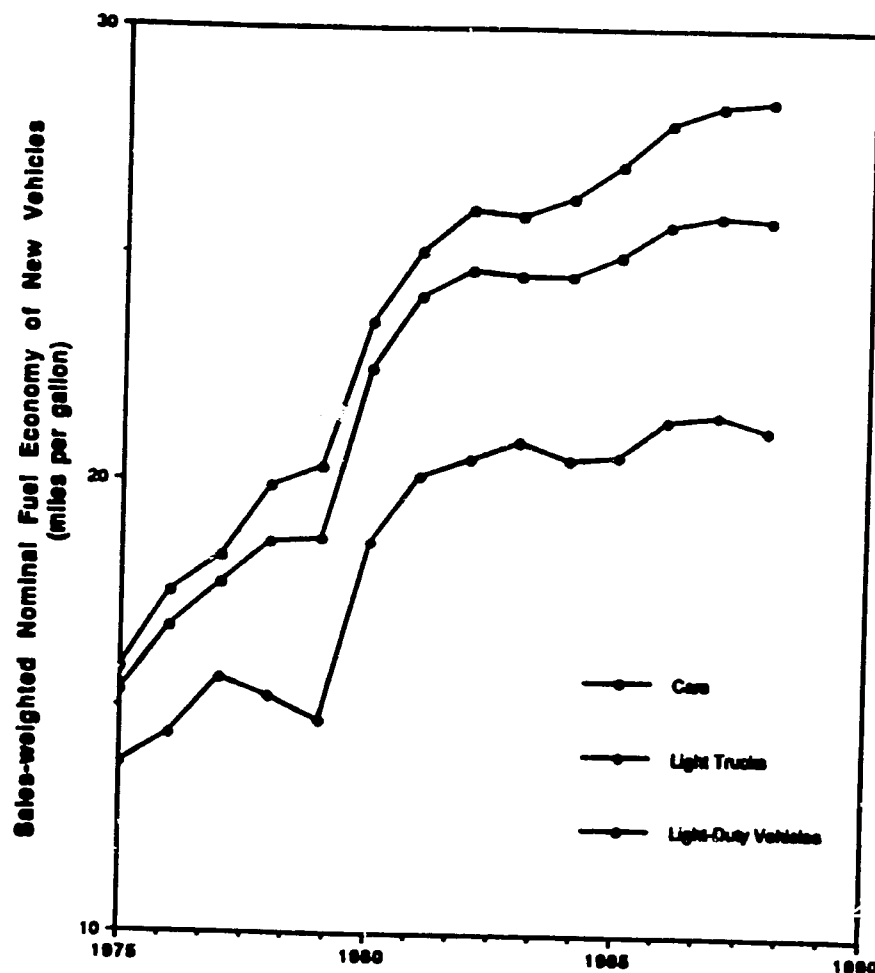


Figure 4 Sales-weighted fuel economy of new automobiles and light trucks (domestic and foreign) and the composite fuel economy of both. The nominal 55%/45% city-highway fuel economy is shown. Source: (16, 17)

What happened within each size class is that new models with higher fuel economy were introduced, replacing or taking market share from old models. In recent years, this process has weakened in the compact and subcompact classes, especially for foreign cars. This weakening explains the slowed progress in fuel-economy improvement for cars since 1982, shown in Figure 7. The introduction of models with higher fuel economy has continued in the intermediate and large classes, explaining the recent improvement.

The progress in each size class (sales-weighted average) is shown in Figure

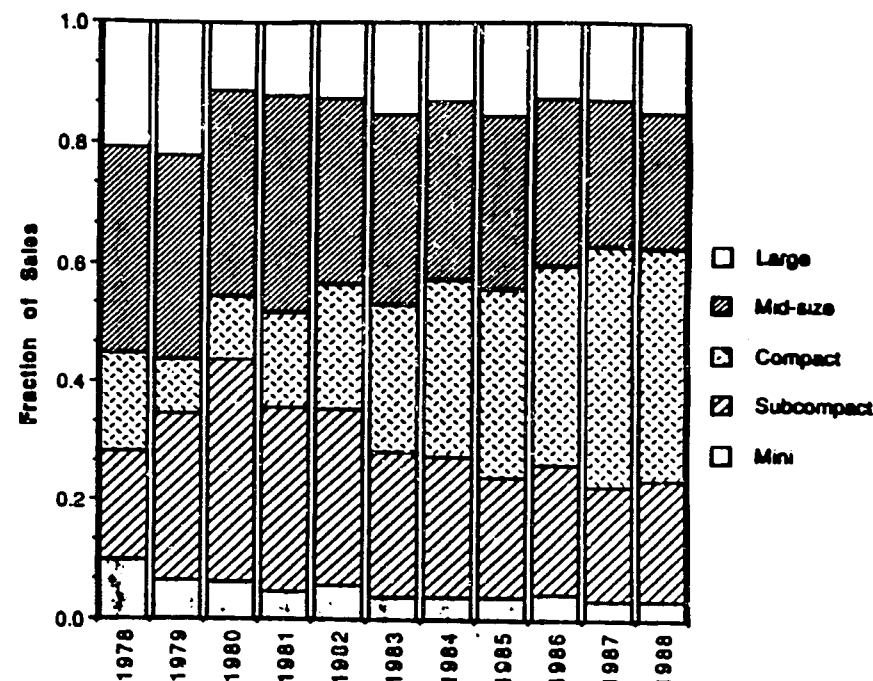


Figure 5 Fraction of sales per automotive size class (EPA interior volume basis). Figure inspired by (18), data from (19, 20)

8 for four car sizes and all six truck sizes. The failure of most of the truck classes to improve as much as the cars is evident. Much more of the improvement in the overall fuel economy of trucks was due to the shift in sales to smaller vehicles, a shift that accompanied the boom in passenger light trucks, than was the case for cars.

Design, Engineering, and Trade-offs

The major fuel-economy improvements in the past decade can be grouped into three components: propulsion-system engineering, other elements of vehicle design, and trade-offs.

Engineering improvements are exemplified by the remarkable 36% increase in power per unit of engine size, or displacement (Table 6). Engine displacement has long been used as a surrogate indicator of power, but engineers have found many ways to loosen the connection.

Through improved design and use of new materials, the ratio of weight to interior volume of cars has been reduced an average of 16% over the past

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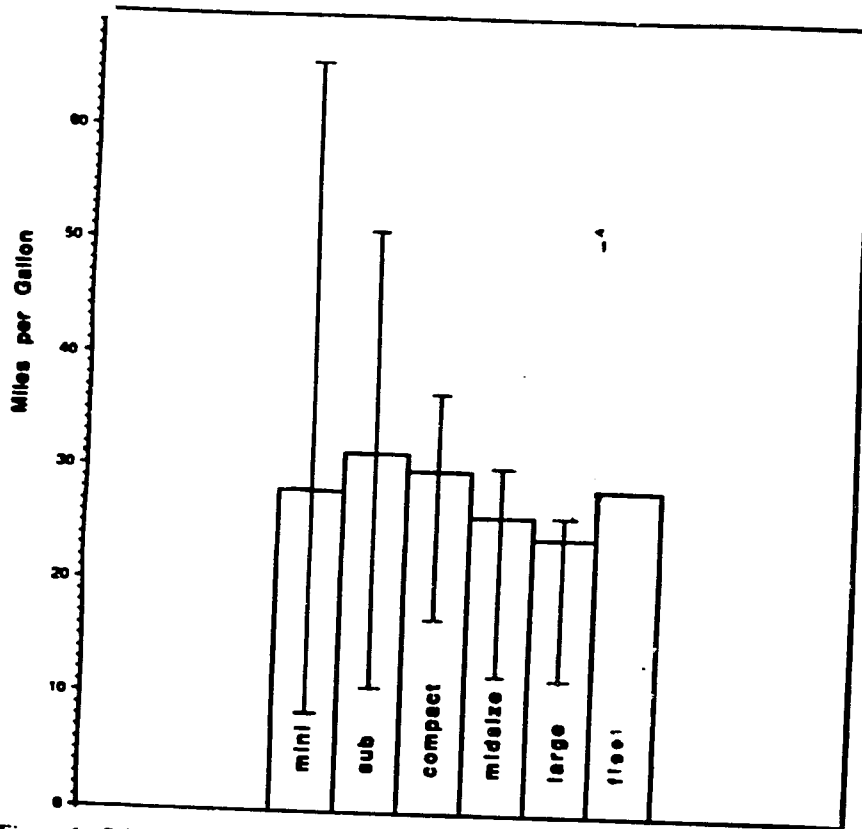


Figure 6 Sales-weighted fuel economy of cars by size class (nominal fuel economy, EPA interior volume classes). Bars show the highest- and lowest-fuel-economy models in each class. Source: (16, 17)

decade (Table 6). Weight reduction has, of course, been a major element in fuel-economy improvement.

Trade-offs among performance, emissions, cost, safety, and fuel economy have also been used by manufacturers in meeting their goals and by buyers in meeting theirs. The significant reduction in acceleration time since 1982, shown in Table 6, is such a trade-off. Cars with higher acceleration performance are attracting buyers.

To estimate the importance of the trade-off between acceleration performance and fuel economy in recent cars, several popular cars were selected and the performance data for different models of each car were studied (models with different or modified engines but the same body) to obtain a statistical relationship between fuel economy and 0-60 mph acceleration

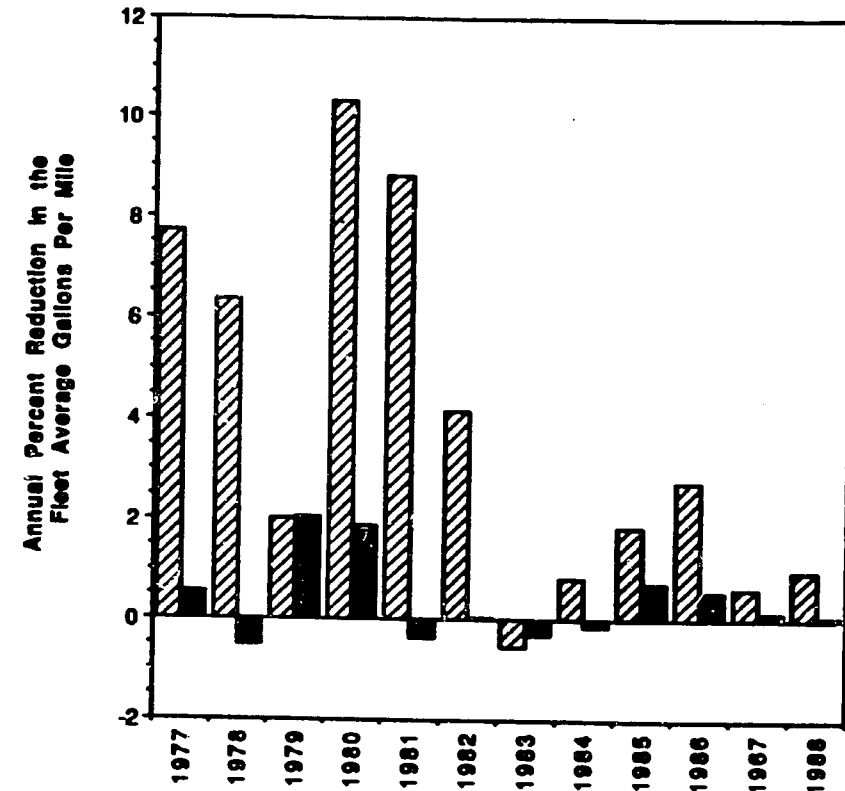


Figure 7 Divisia decomposition of the change in the sales-weighted fuel economy of all new automobiles. The decomposition is of the annual reduction in gallons per mile into the part due to fuel-economy improvement in each size class (hatched bars) and the part due to increased market shares for the smaller size classes (dark bars). Data from (20)

time. The relationship found is that fuel economy is roughly proportional to the square-root of acceleration time. Thus, other things being equal, the reduction in average (sales-weighted) acceleration time from 14.4 s in 1982 to 12.9 s in 1987 caused a decline in the fuel economy of new 1987 cars from a hypothetical 29.6 mpg to the actual 28.0 mpg (a 5% decline).

This analysis underestimates the fuel-economy benefit of designing vehicles with smaller engines. The fuel consumption in idling is roughly proportional to engine displacement, and idling and low-power output dominate urban driving. Through transmission management one can enable a smaller engine to provide good acceleration at low to moderate vehicle speeds, but manufacturers are designing vehicles with extraordinary acceleration capability as a marketing strategy.

MILES PER GALLON

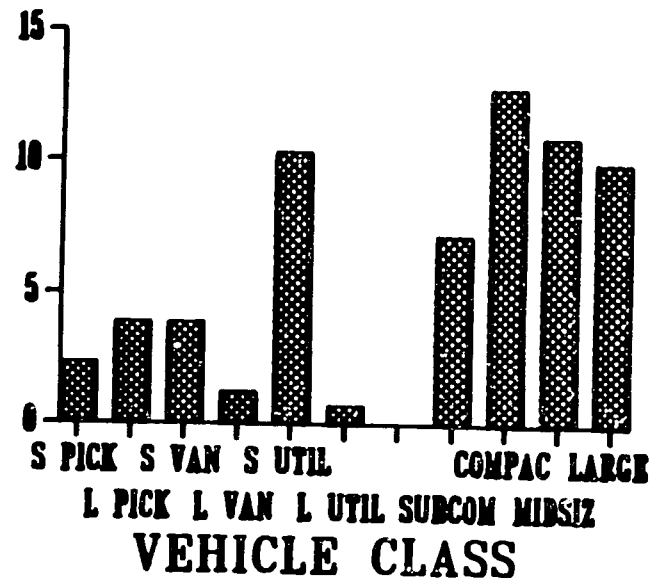


Figure 8 Change in light truck and automobile fuel economies from 1976 to 1987 by vehicle class, with six light truck classes shown at left and four automobile classes shown at right. See (2) for definitions of the classes. Source: (21)

The trade-off between fuel economy and cost in the context of contemporary vehicles cannot be reliably determined from the prices of vehicles, because typical production models with higher fuel economy are cheaper rather than more costly. There are two related reasons: (a) Marketing concepts dictate that high fuel economy be coupled with the stripped-down model; the customer interested in fuel economy is also believed to be interested in a low-cost vehicle. (b) In many current applications, technology that can improve energy-efficiency (such as weight reduction at a given size, an increased engine power-to-size ratio, and improved part-load performance with a turbocharger) is being adopted in ways that increase acceleration performance rather than fuel economy.

The In-Use Fuel Economy of the Entire Fleet

The Environmental Protection Agency determined in the early 1980s that vehicles in use achieve 10% lower fuel economy in actual urban driving than in the urban cycle test for new vehicles, and 22% lower fuel economy in actual highway driving than in the highway test (22). Regardless of age, well-maintained vehicles achieve about 15% lower fuel economy in use than the new nominal vehicle rating: New-Vehicle Composite Fuel Economy =

Table 6 Some average characteristics of new cars*

	volume weight (cu. ft./ton)	power displacement (hp/cu. in.)	acceleration 0-60 mph (seconds)	power curb weight (hp/lb)
1987	70.4	.731	12.9	0.037
1986	70.5	.694	13.2	0.036
1985	69.8	.672	13.3	0.036
1984	69.7	.637	13.8	0.034
1983	70.1	.615	14.0	0.033
1982	69.4	.609	14.4	0.032
1981	68.9	.594	14.4	0.032
1980	67.1	.583	14.3	0.032
1979	62.6	.545	13.8	0.034
1978	60.8	.538	13.7	0.034

* domestic and imported, sales weighted
Source: (16)

$[\text{.55/urban} + \text{.45/highway}]^{-1}$, where urban and highway here refer to the corresponding laboratory fuel economies. This composite fuel economy is the new-vehicle fuel economy quoted throughout this report, except where specified otherwise.

It is now believed, although without solid statistical evidence, that the discrepancy between the typical new-vehicle in-use fuel economy and the nominal rating has increased to as much as 25%. Reasons for an increasing disparity are: increasing urban congestion, increasing share of urban driving, higher speeds on open highways, and higher levels of acceleration. In connection with the latter, some powerful vehicles are being described as cycle busters. Their high power enables them to be driven far outside the test cycle regimes, probably with poor fuel economy, but they incorporate features enabling them to obtain a satisfactory rating.

The other consideration in linking a history of new-vehicle fuel economies (FE_i , where i is the year) to the in-use fuel economy of the entire fleet, is the miles of travel of older vehicles. For this a simple approach is to use 1982 survey data (6). Analysis of these data yields the fraction VM_i of total vehicle-miles traveled by vehicles in each age group (i being the age of the vehicle). The in-use fuel economy of the fleet in 1987 is thus:

$$0.85 \times \left(\sum_i VM_i \right) \left(\sum_i VM_i / FE_i \right)^{-1}$$

The analysis of the connection between the nominal new-vehicle fuel economy and that of the entire US fleet shows that the in-use fuel economy of all automobiles in 1987 was about 18 mpg, far below 28.3 mpg, the 1987

nominal new-car fuel economy; 24.1 mpg, the in-use fuel economy of new cars (using a correction factor of 0.85); or 22.0 mpg, the in-use fuel economy of new light-duty vehicles (16, 17). The rapid advances in new-vehicle fuel economy made in the late 1970s and early 1980s are still working their way through the system. Many old low-fuel-economy vehicles are still being driven.

Let us turn from this record of past progress to consider the possibilities for further increases in fuel economy.

TECHNOLOGY FOR FURTHER FUEL-ECONOMY IMPROVEMENT

There are many options for improving fuel economy. Moreover, many of the options are alternatives to each other. There is not a single path to high fuel economy at this time. In addition, some technologies for improving fuel economy can also reduce emissions. Others can increase them. Many of the technologies also provide performance benefits. The potential for combined benefits has become critically important.

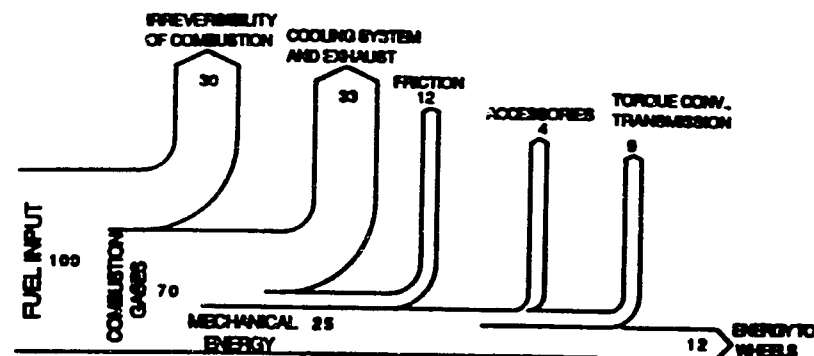
The energy-efficiency of vehicles can be improved in many ways, because energy uses and losses occur in many ways (Figure 9). Energy use can be analyzed in terms of *the energy loads* that arise in operating the vehicle, i.e. what the drive wheels must accomplish, and *the efficiency of the engine-transmission system*, which converts fuel and provides energy to the drive wheels as it is needed. The term efficiency can be applied to the engine and transmission, given the load, but not to the loads.

The lower half of Figure 9 shows that air resistance, tire resistance, and braking loads are comparable in urban driving. In high-speed driving, air resistance dominates. The upper half of Figure 9 shows that only about 12% of the fuel energy in the tank reaches the drive wheels. There are many losses. One of them is not usually acknowledged in discussions of this kind: According to fundamental principles, the process of combustion in itself decreases the quantity of work that can be obtained from fuel energy by about 30% (23). This is due to the irreversibility of combustion, the degradation of energy, reducing its availability to do work. Perhaps this surprising result will seem more reasonable if one considers the extreme case of low-temperature combustion; in low-temperature combustion very little work (such as rotational energy) could be extracted from all the heat generated. If instead of burning the fuel, the fuel energy were converted into electricity, in a fuel cell, this loss of available work could be avoided in principle.

The Efficiency of the Engine-Transmission System

Although the fuel economy and power-to-weight ratios of engines have been much improved in the past 15 years, much more can and is being achieved.

ENGINE-TRANSMISSION SYSTEM



LOADS ON THE VEHICLE

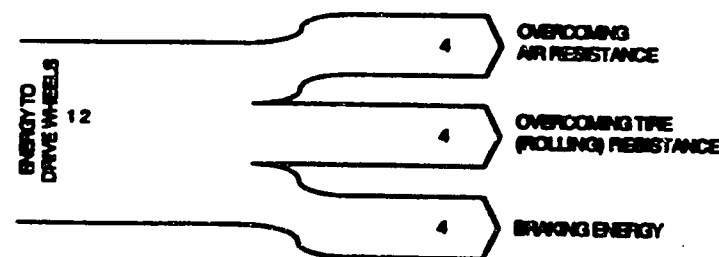


Figure 9 Flows of available energy in operating a typical car in the federal test procedure (urban driving cycle). Available energy is the capacity of the energy in question to do work. Source: (23, 24)

In today's engines about half or more of the calculated power output of the corresponding idealized engine is lost because of cycle losses, friction, and pumping losses (24). Cycle losses are due to heat loss, to the finite time for combustion, and to the finite times for filling and exhausting the chamber. These losses distort the ideal thermodynamic cycle. With the advent of powerful microprocessors and sensors, it is becoming possible to optimize the timing of the spark and the air-to-fuel ratio to reduce these losses. Electronic controls of the current generation typically respond to measurement of state variables like average air intake, temperature, and engine speed and send out signals for modifying the air-to-fuel ratio and spark timing based on encoded tables describing how a typical engine should operate. A new generation of controls involves feedback. Control is based on the sensing of state variables plus output characteristics like exhaust composition, the timing of peak

pressure in each cylinder, irregularities in speed, and knock (25). The feedback capability enables optimization of performance even if sensors or actuators have drifted in calibration, and even if the particular engine differs from the standard. Early versions of such closed-loop controls are now being installed in some production models (26).

The pumping loss is the energy to pull the air-fuel mixture into the cylinder and push out the exhaust. Unless a vehicle is being accelerated rapidly, relatively little power compared to the engine's capacity is needed (27). When power requirements are low, unless gears are shifted so the engine speed can be reduced, less cylinder pressure needs to be generated with each power stroke. This is achieved by burning less fuel. But, for the typical spark-ignition engine the air-to-fuel ratio must be kept within narrow bounds for proper combustion, so less fuel means that less air can be admitted. This is achieved by restricting the air flow, i.e. by throttling. At full load, i.e. with wide-open throttle, pumping losses are relatively small. At moderate load, such as steady highway driving, they are 30% to 40% as large as the engine power output (24).

There are a multitude of proposals and prototypes for reducing throttling losses. One approach is to manage gear ratios so that when the engine delivers low power then its speed is low, so it operates as near wide-open throttle as possible. Such transmission management could be achieved with continuously variable transmissions, for example. A similar result can be achieved by not fueling and firing some of the cylinders at low load. Another possibility is to use a smaller engine, that in normal operation delivers relatively little power, but that can, by delivering the charge under pressure (e.g. through supercharging), provide a lot of power. Such an engine is optimized for typical rather than maximum power requirements. Yet another option is variable control of the intake valves such that at low load the air intake occurs for only a suitable fraction of the intake stroke (28). Throttling is thus largely avoided.

The type of engine that has been in use for many decades is already highly refined and so is more difficult to improve than those in a low state of development. While significant improvements in controls, friction reduction, and part-load strategy are still possible with the typical gasoline engine, really large improvements may require substantial departures. Paradoxically, however, any radical departures will have to compete with the highly developed engines we already have—implying that a great deal of careful development will be needed before any substantially different engine could become competitive.

Among the alternative engine concepts is the direct-injection diesel, in use in some production models and prototypes in Europe. In R&D is the more radical ceramic-coated diesel, with some ceramic parts, which would be

operated at much higher temperatures, with the extra energy in the exhaust gas captured to achieve high efficiency.

An exciting spark-ignition engine initiative is the lean-burn (high air-to-fuel ratio) two-stroke engine. The two-stroke is currently used in small engines, such as for lawn mowers, and in many marine applications. As noted above, the power output of standard automobile engines has been increased in the last decade for a given displacement, while emissions have been sharply reduced. These benefits have been achieved through many refinements and complications, as anyone over 30 knows who looks under the hood. Such refinements have not yet been incorporated in the two-stroke engine.

The two-stroke engine has twice as many power strokes in a given number of revolutions as the four-stroke and in its basic version has no valves, only ports, which are uncovered as the piston moves. A three-cylinder engine could have almost the same output as a six-cylinder four-stroke engine (of twice the displacement). Saab used such an engine (in unmodernized form) in the 1960s, and cars with them are manufactured in East Germany. This two-stroke engine would be light enough to be carried by a strong person; and it would be relatively cheap and easy to maintain.

But would it be possible to achieve low emissions and high fuel economy by refining the two-stroke engine? Development work is now under way by engine manufacturers around the world. Extraordinary improvements in the fuel economy, emissions, and misfire performance have already been achieved, compared to two-stroke engines of the past, with modern fuel injection systems (29–31). It is not clear where this development work will lead. For application as a small automotive engine, will supercharging be essential? What level of catalytic clean up of the exhaust will be necessary? How simple, light, and cheap will the resulting engine be?

Fuel-Economy Emissions Interactions

In the context of 1988 markets and political climate, the most important possibility for much higher fuel economy may be technology that couples fuel economy with emissions reductions. Many people have the misconception that emissions reduction and fuel economy are antithetical, because, given a vehicle design, if you would reduce emissions you must add equipment or make adjustments that will decrease fuel economy. In designing a new vehicle, the opposite relationship can occur. New technology or fundamental redesign often offer opportunities to both improve energy-efficiency and reduce emissions.

A major fuel-economy tie to emissions reduction arises from the nature of the mass regulatory-standards for emissions, i.e. the limits on grams of emissions per mile (32). A vehicle that consumes relatively little fuel per mile has an easier-to-meet standard in percentage terms (concentration of pollut-

ants in the combustion gases). Emissions decrease less than a simple proportion of fuel use would suggest, however, with, e.g. a smaller engine.

In addition, some fundamental approaches to fuel-economy improvement also enable percentage emissions reductions. As an example, consider a lean-burn engine. With lean-burn, the combustion temperature is lower, reducing NO_x formation, as shown in Figure 10. The fuel-efficiency is nevertheless improved, because air is a better thermodynamic medium than (evaporated) gasoline. The increase in unburnt hydrocarbon with air-to-fuel ratio, which begins at the right of Figure 10, is a major challenge. It can be prevented, in principle, by improving ignition, e.g. through a higher-energy ignition mechanism, and it can be mitigated by improved exhaust after-treatment.

It is possible that a lean-burn engine can be developed with relatively low emissions, with little or no after-treatment, e.g. without a catalytic converter.

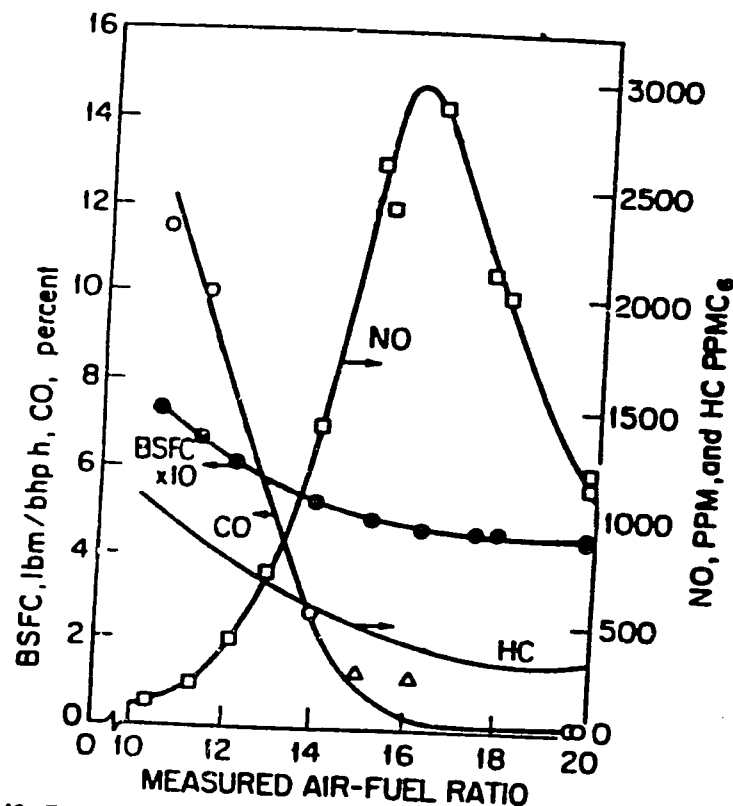


Figure 10 Exhaust gas composition and specific fuel consumption of a sample automotive engine, vs air-to-fuel ratio. The stoichiometric ratio is 14.6. Courtesy of Donald J. Patterson.

ENERGY AND TRANSPORTATION

In a very high fuel-economy vehicle, such a system might be able to meet strict emissions standards. One disadvantage of this approach is that there is no practical after-treatment to reduce NO_x in an oxygen-rich environment, so that the control of NO_x would have to be achieved entirely in the engine.

Reduction of the Vehicle Load

The load has three components: energy that goes into braking, air resistance, and the tire, or rolling, resistance. A general approach to reducing braking and rolling resistance is weight reduction. Improvements in design and increasing use of lighter and stronger materials (plastics, composites, high-strength steels, and aluminum) are continuing. To recover energy that would otherwise go to the brakes requires an energy storage scheme, such as braking through a motor-generator that charges batteries, or braking by transferring energy to a flywheel. At present, these appear to be costly options for a small vehicle. Dramatic reductions of air drag are now going on as designers learn how to create the appropriate smooth surfaces and integrate them into the vehicle (26). Where the average coefficient of aerodynamic drag of 1979 model US cars was 0.48, the Taurus/Sable has a drag coefficient of 0.30 and prototype vehicles have coefficients of less than 0.2. Rolling resistance was sharply reduced with the introduction of radial tires. Further improvements are in development (26), but are limited by the primary need for tires to hold the road.

In this brief summary, many important measures that could be (or already are being) used to improve fuel economy have not been discussed, or have been mentioned only in passing. The point is that there is an extraordinary ferment in automotive technology at this time. It is due to the conjunction of new capabilities in materials, information, and control, which affect design and manufacturing as well as the vehicle itself. What will be the impact on fuel economy? Let us briefly examine the influence of the marketplace.

ECONOMICS AND FUEL ECONOMY

Through improved design and technological innovation, the loads on a vehicle can be reduced and the energy-efficiency of the propulsion system increased without necessary detriment to vehicle size, performance (e.g. acceleration), safety, and emissions. In addition, trade-offs can be made among fuel economy, size, acceleration performance, cost, safety, and other characteristics. In today's market conditions, two kinds of change in the fuel economies of new vehicles can be expected: (a) modifications to existing or planned production models and (b) creation of substantially different vehicles.

Modifications to Current Models

Technologies to improve fuel economy, which are already developed or whose development is of low risk, and were, in 1985, considered likely to be incorporated by domestic automobile manufacturers into existing and planned models, are the basis for a cost estimate by Energy and Environmental Analysis, Inc. (33). As shown in Table 7, a \$48 per vehicle price increase is typical for each one mpg improvement in the fuel economy of a current compact car. The modifications considered are listed in Table 8. The corresponding cost of saving gasoline, starting with today's typical new vehicle, is less than 50 cents per gallon saved—decidedly less than the price of gasoline. (A 10% real discount rate, a vehicle lifetime of 10 years, and an average of 11,600 miles per year of driving are assumed.)

Appropriate combinations of the cost-effective technologies considered in Tables 7 and 8 are capable of changing the current compact cars, with fuel economy of about 30 mpg, into cars with fuel economy in the mid-40s or higher.

These costs are based on estimates of the manufacturing costs (materials and labor) multiplied by the average long-term ratio of vehicle retail price to manufacturing cost. This ratio is four to five. It accounts for all other costs: R&D, plant and equipment, tooling, administration, and all distribution and sales costs, as well as earnings.

The reader has to be careful in interpreting these numbers. As discussed above, the price of typical vehicles declines with increasing fuel economy, because in a high-fuel-economy model the engine system is simpler than one

Table 7 The cost of near-term technology to improve automotive fuel economy*

Typical fuel economy for application (mpg) ^b	Retail price increase per vehicle for one mpg improvement in fuel economy (1986 \$)	Total cost per gallon saved ^c (\$/gal.)
30	48	\$0.46
40	46	\$0.77
50	37	\$0.98

* Adapted from Energy and Environmental Analysis, Inc., "Analysis of the Capabilities of Domestic Auto Manufacturers to Improve Corporate Average Fuel Economy," Appendix A (compact cars), Ref. 32.

^b The 30, 40, and 50 mpg descriptions are nominal; they correspond to technologies listed by EEA as being incorporated in 1986-1988, 1989-1991, and 1992-1995, respectively. See Table 8.

^c Value of the incremental retail price of the vehicle at the time of gasoline saving, per gallon. For application at 30 mpg, the cost is $0.85 \times 48 \times 1.4 / [(1/30) - (1/51)] \times 116,000$, where 85% is the in-use fuel economy compared to nominal, 1.4 is the appreciation of the incremental cost of the vehicle using a 10% real discount rate, and 116,000 the expected mileage in the first 10 years of automobile life.

Table 8 Sample technologies considered in the cost estimate*

	Increased fuel economy (percent)
Technologies introduced 1986	
weight reduction at constant size (materials substitution)	7
rolling resistance reduction (improved tires)	4
reduced aerodynamic drag	3
engine-efficiency improvements	
friction reduction (especially piston and rings)	4
improved lubricants	2
multi-point fuel injection	7
new engine designs—fast-burn cylinder	4
four valves per cylinder	8
roller cam followers (reduced friction in moving valves)	3
accessory efficiency improvement	2
front wheel drive	12
Technologies introduced 1989-1991	
optimization of transmission	
electronic transmission control	3
automatic overdrive	8
Technologies introduced 1992-1995	
engine-efficiency improvement	
diesel	45
intake valve control (variable valve timing)	8
optimization of transmission	
continuously variable transmission	12

* Some technologies, although briefly named, represent a complex of design changes. The timing for introduction of technologies in specific models is that forecast by Energy and Environmental Analysis. This is not a complete listing. Moreover, some technologies can be improved with time. On the other hand, some are mutually exclusive, have limited applicability, or have already been partially applied. One cannot simply combine the percent improvements. See the original references for many of the details. Source: (32, 33)

souped up for high acceleration performance and the design is less luxurious. In contrast, incremental costs are shown in Table 7, the average cost of modifying given vehicle models to increase their fuel economies. Typically these improvements do not require loss of acceleration-performance or reduction of interior volume, although there is weight reduction. (Some loss of acceleration performance would, however, probably characterize diesel engines, if adopted.)

Finally, and of great importance, the incremental cost of these technologies, as calculated here, does not mean that the preferred fuel-economy technologies will ultimately cost as much. Fuel-economy technologies have been costed here as add-ons, additional parts, and fabrication steps in the manufacture of existing automobile models. When the technologies are

integrated into the design and manufacture of new vehicles, it is likely that the incremental cost of the fuel-economy benefits will be much less.

Altogether New Vehicles

The highest-fuel-economy vehicles already in production have impressively high mpg ratings, but tend to be rather small vehicles with low acceleration performance. Some more ambitious prototype vehicles are shown in Table 9. Many incorporate radical innovations, such as aluminum bodies and engines (GM), direct-injection diesels that stop when the vehicle coasts or stops, and start as needed (VW & Renault), and direct-injection diesels with continuously variable transmissions (Toyota). Extensive use of plastics and light metals characterizes all these prototypes. The potential improvement suggested by prototypes is difficult to evaluate because they are often single-purpose projects. A practical, marketable vehicle may involve many compromises. The cost and performance that cars like these would have if designed for the market and mass produced remain to be determined. There is, however, every expectation that cars with very high fuel economy and good space and performance characteristics can be built, perhaps without a substantial cost penalty beyond the manufacturer's initial tooling investment (27, 35).

Table 9 High-fuel-economy prototype vehicles*

	Curb weight (lbs)	Power curb wt. (hp/lb)	Fuel economy ^b (mpg)	Prototype status
2-4-passenger				
GM TPC	1040	0.037	66	complete
Volvo LCP 2000 diesel	1555	0.033	70	complete
Renault Vesta	1047	0.026	89	complete
4-passenger				
Volkswagen E80 diesel	1540	0.033	83	development
Peugeot ECO 2000	990	0.028	79	development
4-5-passenger				
Volkswagen Auto 2000 diesel	1716	0.031	66	complete
Renault EVE+ diesel	1880	0.027	70	complete
Peugeot VERA+ diesel	1740	0.029	66	development
Toyota AXV diesel	1430-target	0.039	97	development

*Ref. 26

^bFor gasoline vehicles measured with a standard test, adjusted as per Ref. 22. For diesel vehicles, unadjusted

The Market and Fuel-Economy Improvements

How likely is the implementation of major fuel-economy increases in the next decade or so? There is technological momentum for incorporating some of the modifications listed in Table 8, at the typical costs shown in Table 7. On the basis of the cost advantages to consumers, Energy and Environmental Analysis projected in 1985 that many of these improvements will be made by domestic manufacturers by 1995. But with today's fuel prices and fuel-price expectations, these projections appear overoptimistic.

Two principal reasons for lack of urgency on the parts of manufacturers and car buyers are evident from the "von Hippel-Levi effect," Figure 11: (a) The contribution of fuel purchases to the cost of driving is, at present, relatively small—it is less than the cost of insurance. (b) The curve representing total cost vs fuel economy varies only slowly with fuel economy; the vehicle buyer can be expected to be indifferent over a broad range of fuel economy (36). For example, if a person drives 12,000 miles per year and his/her car is improved from 30 to 40 mpg (nominal), then 120 gallons of fuel are saved annually. If the cost of saved energy is 60 cents per gallon (between 46 and 77 cents, Table 7) and the cost of fuel is \$1.00 per gallon, the net value of the saving is about \$50 per year, a small motivation. Moreover, the simple payback on the increased price of the vehicle is about four years, somewhat long in terms of consumer behavior. (The annual operating savings are 120 gallons or \$120, while the increase in the up-front cost is, from Table 7, about \$470.) In other words, while the nation may have a great interest in reducing total petroleum use and some geographical regions may be very concerned with reducing fuel use by vehicles in order to reduce air pollution, the individual has very little interest, in simple economic terms, in the fuel economy of the vehicle he or she buys.

Without a stimulus other than fuel saving, the manufacturer would be even less inclined to make high-fuel-economy vehicles than the consumer to buy them in today's market. A manufacturer would incur a significant technological risk and substantial opportunity costs in introducing new fuel-efficient technology. He is very unlikely to do this if his prospective buyer is likely to be indifferent about the new product.

Events, however, could alter this pattern of inertia. There are three important kinds of possible events: (a) new technology with multiple benefits, one of which is fuel economy, (b) much higher fuel prices and/or fuel shortages, or (c) strengthened fuel-economy regulations or other changes in public policy with strong fuel-economy implications.

Technology with multiple benefits may become part of the program of manufacturers for whom innovation is a major competitive strategy. Consider one fuel-economy innovation, the continuously variable transmission. The

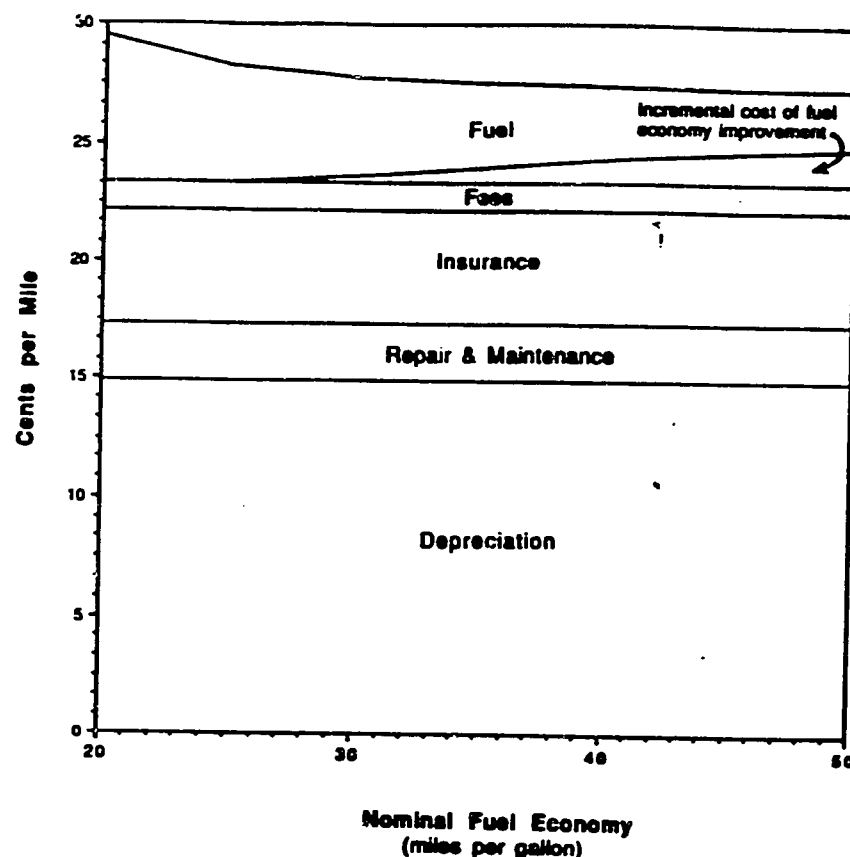


Figure 11 The cost of owning and operating a midsize car vs fuel economy. The data at left are for 1988 midsize cars (where average in-use fuel economy is 23 mpg) from the American Automobile Association (6). The incremental cost is taken from Table 7. The depiction of several costs as independent of the fuel economy of modified vehicles is somewhat arbitrary. Some argue that costs will fall, e.g. that lighter plastic components will be more durable and thus decrease depreciation; others argue that costs will rise, e.g. that the vehicle will require more maintenance because it is more finely tuned.

driver gets a different feel during acceleration. Such a technology could establish new standards of performance, creating demand for cars that also have high fuel economy.

A different kind of technical change would be creation and wide adoption of a narrow two-passenger vehicle as an extra vehicle for use in commuting and errands. A relatively safe, high-performance vehicle could probably be manufactured. Two factors make wide adoption of such a vehicle conceivable: (a) Rising incomes in many households and rapidly increasing vehicle

life are encouraging purchase of "excess" vehicles, often special-purpose vehicles. In 1983, 13% of all vehicles were already in excess of the number of drivers in the household (15). (b) A small high-performance vehicle, if afforded special parking privileges, might have appeal. There is a tremendous fashion for pickup trucks as passenger vehicles; and many of these are two-passenger vehicles. Of course, even though a very small two-passenger vehicle might have a social rationale, it might not appeal to buyers.

Fuel price increases would also motivate fuel-economy increases, but the effect is not thought to be strong (37, 38). It has been estimated that the price elasticity is -0.5 for the fuel economy of new car purchases. That is, for every 10% increase in fuel price, the average buyer would opt for a vehicle with 5% higher fuel economy. But this analysis probably overestimates the impact fuel price increases would have in the United States, because the present level of fuel economy is primarily due to the regulatory standards. A major increase in fuel economy would require fuel price increases of a factor of two or more, fuel shortages, or major changes in public policy.

PUBLIC POLICY AND FUEL ECONOMY

A Review of Recent Initiatives

Before addressing future policies that could lead to major fuel-economy improvements, the policy experience gained in the past dozen years is briefly reviewed.

INFORMATION The federal government systematically determines the fuel economy of each vehicle model every year, publishes the information in the Gas Mileage Guide, and has a window sticker put on each new vehicle. Although the in-use fuel economy varies considerably among individual vehicles of the same model (as maintained and driven), this information is reliable enough for buyers and has removed the extensive confusion that characterized fuel economy before the age of a standardized laboratory test.

PERFORMANCE REGULATIONS The mandated improvement of corporate average fuel economy (CAFE) was probably largely responsible for the approximate doubling of the new car fuel economy from 1974 to 1986, although some argue that fuel price increases alone would have driven a similar increase. The history of the sales-weighted fuel economy of new cars, when compared with the history of CAFE regulations and the price of gasoline (Figure 12), leaves little doubt as to the engine that drove the improvements. In examining the figure, note that the 1970 gasoline price was a little higher than that in 1973, that the CAFE standards were legislated in 1975, calling for an increase to 27.5 mpg by 1985, and that fuel price

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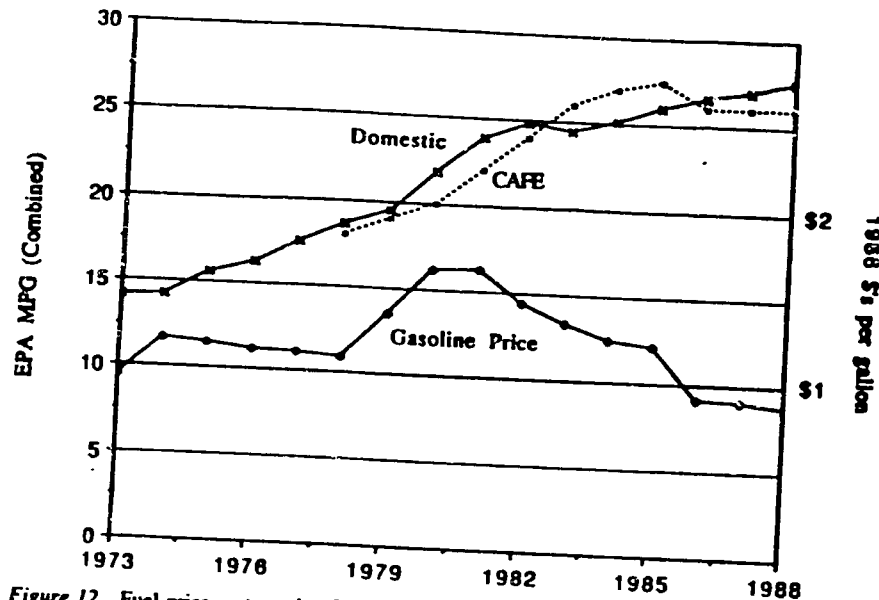


Figure 12 Fuel price, automotive fuel economy, and the CAFE standards 1973-1988. In the period before 1973 the real fuel price declined gradually. Source: (39)

elasticity studies suggest an elasticity substantially less than one, rather than greater than one.

No further increases in fuel economy are mandated, although the 27.5 mpg standard for cars remains. The 27.5 mpg standard has not yet been fully imposed, however, reductions being granted on petitions from Ford and General Motors. There are also standards for trucks, but these are not set by the legislation as such; they have been set largely in conformity with manufacturers' wishes.

Of the arguments now offered against further increases in the CAFE standards, one is especially powerful: that CAFE standards discriminate against corporations offering a full line of vehicles (including large ones). Modifications that have been suggested are: mandating a percentage improvement for each corporation and mandating a certain improvement for size-weighted fuel economy (40).

THE GAS-GUZZLER TAX The average fuel economy of vehicles purchased can be improved by a carrot or stick at the time of purchase. The gas-guzzler tax has this purpose. It kicks in at \$500 for cars with fuel economy below 22.5 mpg and grows to more than \$3000 for a fuel economy below 12.5 mpg. In 1986 the US Treasury collected \$148 million, as the program came into its final form.

FUEL TAXES In the United States, motor fuel taxes average 23 cents per gallon and have little impact on which vehicles are purchased and relatively little impact on how much vehicles are driven. Modestly higher fuel taxes might influence owners of inefficient cars to trade them in earlier. Unfortunately, this process might not hasten the time when inefficient cars were scrapped. What would be likely to happen is what happened in the late 1970s: The prices of used cars with low fuel economy were depressed so they were bought and used by people for whom the low first cost was a strong attraction.

Fuel taxes in the United States have not been conceived as influencing purchases of light-duty vehicles. In many other countries, however, gasoline taxes are several times higher than the 23 cents per gallon average here (41). The \$2 to \$4 per gallon price of fuel in Europe does have a major impact on vehicle purchases and use. A definitive study of the European experience, however, would also have to take into account the much higher population density and geographical structure, which discourages the long-distance commuting by personal vehicles that is common in the United States.

RESEARCH AND DEMONSTRATION The Department of Energy has an ongoing R & D program in Transportation Energy Conservation. The 1987 appropriation was \$56 million. The program is limited to work on radical propulsion systems, especially ceramic diesels, gas turbines, and electric vehicles, and in advanced materials, especially for engines. There is a general sense about this program that, although important transportation product goals, such as an electric vehicle, have not been achieved, some basic yet practical work has been done, especially on ceramics and batteries, which may have considerable economic value. The existing program is much smaller than the Cooperative Automotive Research Program, an R & D program including substantial basic research, proposed during the Carter administration, but not implemented.

The Rationale for Public Policies to Increase Fuel Economies

Concerns for national security relative to petroleum supply and for the well-being of the economy in the face of increasing energy prices, have justified public policies aimed at energy-efficiency. Concerns for metropolitan air quality, and to a lesser extent regional air quality, have justified the emissions standards.

The petroleum-supply issues remain important in spite of the current low price because of our rapidly increasing dependence on imports (caused by the low price). Net imports of petroleum are rising toward 40% of consumption, a higher level than that of 1973, before the first oil shock, and close to the 45% level of 1978, before the second oil shock.

Air quality concerns are increasing because (a) metropolitan air quality

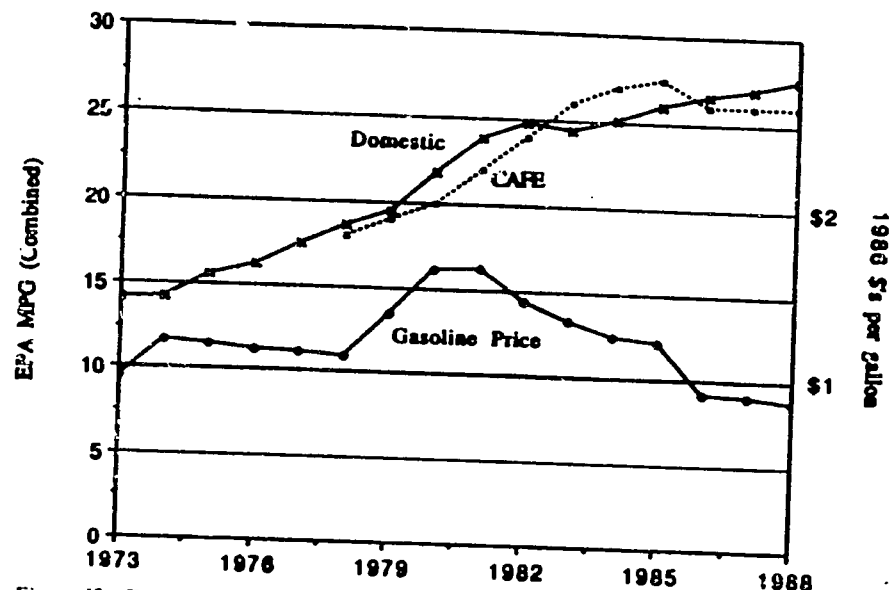


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Air quality concerns are increasing because (a) metropolitan air quality

continues to be unsatisfactory in many areas, and the public is clearly interested in making progress; (b) regional air quality impacts, especially acidification of lakes and forest death, are increasingly troubling; and (c) the greenhouse effect will affect the global climate, as a result of increasing atmospheric concentrations of infrared-absorbing gases, such as carbon dioxide, NO_x , methane, and chlorofluorocarbons. The production of carbon dioxide by gasoline-fueled vehicles is inversely proportional to their fuel economy. The joining of these strengthened environmental concerns with those for petroleum supply gives impetus to consideration of stronger fuel economy and emissions policies.

Major Policy Options for the Near Future

INDUCED MOTOR-FUEL PRICE INCREASE Other industrial countries impose high motor fuel taxes with the result that fuel economy is of economic importance to the vehicle purchaser. In the second quarter of 1988, taxes constituted 31% of the price of gasoline in the United States, but 47% in Japan and 63 to 79% in the major countries of Western Europe (41). The higher fuel prices in Japan and Europe may be responsible for the relatively rapid introductions there of fuel-economy innovations.

Under US conditions, a motor fuel tax that might generate a great deal of fuel-economy innovation, on the scale of \$2.00 per gallon, is not feasible in the foreseeable future. The strong dependence of rural areas on cars and light trucks, and the importance of commercial trucking in our economy, suggest that it would be inappropriate to approach fuel-economy improvement primarily through use of a stick that strongly penalizes those who drive a great deal.

A moderate fuel price increase might, however, be a part of a effective package of policies aimed at improved fuel economy. (At this time it seems we could have a moderate motor fuel tax increase for revenue purposes.) Such a package could emphasize technology policies and strengthened standards for new-vehicle fuel economies, but include induced fuel price increases of 25 to 50 cents to provide a balance of motivations. The concept is that the entire cast of players (manufacturers, vehicle buyers, drivers, and those responsible for other components of the system), will be able to respond more effectively if all are motivated. In contrast, if, for example, manufacturers are pressured to bring out higher-fuel-economy vehicles but buyers are wholly indifferent, there would be a dissonance, which might lead people to look for loopholes instead of increased fuel economy.

STRENGTHENED FUEL ECONOMY REGULATIONS The tool of minimum standards for the fuel economy of new vehicles, standards that are periodically strengthened, has worked and would probably work in the future

(especially if used in concert with other policies). Properly designed, it would put all manufacturers on an essentially equal competitive footing. As discussed above, there is good evidence that the overall cost of improvements would be more than matched by savings on fuel, in the fuel-economy range that is likely to be considered and over a time period that allows manufacturers to retool and change models at a typical pace.

A critical component in strengthened standards would be closure of the light-truck loophole. Light-truck performance standards would have to be developed and written into the legislation, instead of being left to the discretion of an agency.

The second half of the 1980s is, however, a time of low oil prices. Under these conditions the political will to adopt a controversial policy of strengthened fuel-economy regulations will probably be lacking. And yet it would be a straightforward, economic, and equitable way to push petroleum-supply problems off into the distant future.

STRENGTHENED AIR POLLUTION STANDARDS Local and regional air pollution problems remain serious a quarter century after the first Clean Air Act (1963). Progress has been made in cleaning up particular sources. For example, measurements of light-duty vehicles in use by the Environmental Protection Agency show that emissions per vehicle have been greatly reduced. The typical model 1988 car in normal use emits roughly one fifth of the hydrocarbons and carbon monoxide and one-third of the NO_x that an early 1970s car emitted per mile (42). Extraordinary progress has been made through the combined efforts of government and the manufacturers. In typical use our light-duty vehicles are very clean.

On the other hand, vehicle-miles traveled have increased about 80% since 1970. In addition, the standards are not completely definitive because non-standard situations may create most of the pollution. EPA is conducting more careful studies of (a) emissions, especially evaporation of fuel rather than tail pipe emissions, in very hot and sunny weather, (b) emissions, especially carbon monoxide, in very cold weather, (c) emissions in high-power (wide-open throttle) operations, (d) emissions in heavy congestion situations, and (e) emissions from vehicles whose emissions control systems have failed. (For the last group inspection and maintenance programs have been introduced in regions not meeting air quality standards. Such programs can work, but are difficult to implement so as to detect and correct most of the gross emitters.)

To develop and exploit the technological opportunities to further reduce vehicle emissions, it would be valuable to strengthen technology policies (such as R&D programs) as well as to enact still more effective air pollution standards. In designing more effective standards more attention to (a) fuel

economy-emissions interactions and (b) nonstandard situations seems called for. It may be that a regulatory focus on further tightening of the grams per mile limitations is not the most effective way to improve air quality. For example, taxes and rebates based on emissions performance might be more effective.

RESEARCH The body of new ideas, systematic knowledge, trained personnel, and instrumentation associated with research activity is the context in which invention and development take place. The strength of the United States in basic science research has persuaded many that our arrangements for research are in good shape, but that is not accurate. As suggested by the recent spate of engineering activity at the National Science Foundation, research in basic engineering or basic technology is very uneven in the United States. The tendency of the private sector to underinvest in research (compared to development) is well established. One of the large holes is research relating to technologies for land vehicles and their manufacture. For example, only recently has research relating to basic properties of combustion begun to be at all adequate. Many issues relating to engines and transmission management need thorough and fundamental examination. In vehicle manufacturing, the forming of metals, plastics, and ceramics is still largely an art rather than a science. It is not enough for manufacturers to apply the new information technology in a general manner; research on problems specific to vehicle design and manufacture must be carried out.

DEVELOPMENT AND DEMONSTRATION The stages of technical change that precede innovation are invention, development, and prototype demonstration. The context for development activity in the United States would be quite different than it is today if there were more active innovation in vehicles.

The federal government should be cautious (in the author's view) about directly supporting development and demonstration of commercial products. The nation has had bad experience with programs like the breeder reactor, synfuels, the electric vehicle, the Transbus, and Operation Breakthrough (manufactured housing). In these cases the project goals and management were far too inflexible for the creation of a commercial product. At present another major demonstration program is under way: clean coal technology. The jury is out in that case.

The pattern is not all one of failure, however. For example, major successes were achieved with partial federal support for demonstration of lighting and window technologies (43). The experience tentatively suggests two criteria for partially federally supported development and demonstration programs: (a) Federal participation in development and demonstration is more likely to be effective if the technology in question is small (with a low cost per

installation) so that different attempts can be made and some failures are expected from the start. (b) Federal participation is more likely to be effective if the technology is generic, i.e. may have a variety of applications.

INNOVATION These days the United States is known for its prowess in basic science research, while Japan is famous for taking research concepts and applying them. The first concern of technology policy must be the vitality of the private sector in adoption of new technology. The technology pull of manufacturers who want or need to innovate is required as well as the technology push of research.

While innovation in motor vehicles is needed, the nation's manufacturers are all large and cautious. The industry has matured to the point that there are no small vehicle manufacturers left. (And the barriers against a new firm entering the business, except from a foreign base, are very high.) Until the threat of innovative Japanese manufacturers became intense, the industry was largely not competing with respect to product or manufacturing innovation (44).

One reason for the manufacturers to be cautious about new technology is the scale of risks that are involved. A typical production line produces 200,000 vehicles per year. Engine lines involve more of a commitment. The tooling costs are large. The manufacturer needs to feel confident that the new product will be successful.

A second reason for caution is that US manufacturers have made several major innovations in the past couple of decades, but have been badly stung several times by poor technological performance. The Japanese may be better at innovating and avoiding the flawed product than we are. As a result they more frequently use innovation as a competitive strategy.

In the face of this problem, a policy to directly encourage innovation is called for. One possibility is government-funded consumer rebates. The rebate could simply be based on fuel economy (45). Another possibility is contests for creation of prototype vehicles meeting certain goals. Over the past century contests for new technological achievements have provoked very interesting creations. This approach could be invigorated with major government-funded contests.

A more refined policy incorporating features of both these approaches would be federal rebates applying to the initial production runs of vehicles meeting specified goals. Different goals could apply to different sizes of both cars and trucks.

It would probably be desirable to carry out such policies in combination: both to encourage consumers to buy early versions of vehicles incorporating new technology and to prepare manufacturers to carry out such technological change (46). In the late 1970s the government presciently helped manufactur-

ers prepare for the second oil shock with the 1975 CAFE legislation (47), but sales of the new vehicles were poor. Would rebates to smooth the way for the new technology have helped? Might the associated economic dislocation have been moderated? One does not know. There has been little evaluation of past policies to guide the formulation of new policies.

OTHER PASSENGER TRANSPORTATION ISSUES

Alternative Fuels

Alternative fuels for personal passenger vehicles is currently a hot topic. With the decline in oil prices and the difficulties of synfuels programs, interest in a synthetic gasoline has declined in the United States, but metropolitan-region air pollution has sharpened interest in fuels composed of simpler molecules, whose products are less reactive in the atmosphere. There are major efforts elsewhere with ethanol, natural gas, and LPG as motor vehicle fuels. At a more theoretical level, interest in hydrogen and electricity continues. (Much developmental work on electric vehicles has gone on in the United States, but there is as yet no hint of practical vehicles for other than small niche markets.)

Methanol enjoys the most attention in the United States at present. Some of this attention is due to the fact that modified vehicles can burn (without attention by the driver) widely varying mixtures of methanol and gasoline, thus potentially easing aspects of a transition to methanol. For example, methanol could be favored in certain air-quality regions and gasoline elsewhere. A disadvantage of this approach is that such flexible-fuel vehicles would not be designed to take advantage of the specific properties of the methanol, a substantial sacrifice. Another approach to flexible fuel capability is presented in the paper by Melde et al (48) in this volume.

Congestion

Metropolitan area transportation is burdened by congestion. Moreover, street and highway mileage continues to grow more slowly than vehicle-miles. Only a small fraction of passenger-miles can be diverted to mass transit in the foreseeable future. Moreover, the energy-intensity of mass transit per passenger-mile may not be much less than that of the private car. Mass transit can, however, relieve congestion and can influence real-estate development so as to reduce dependence on personal vehicles. Some evidence of this is that motor vehicle-miles per adult is two thirds as great in New York and Illinois as it is in Texas. (Another response to congestion, information and control systems for highways, is not discussed.)

Intercity passenger travel faces even more severe congestion. Traveling in three dimensions is, paradoxically, much more affected by crowding than traveling in two. There is a technologically exciting opportunity: high-speed

ground transportation. The concept is to replace short-haul heavily traveled air routes with high-speed ground vehicles. The main focus would be substitution for air travel, including longer-distance travel where a ground trip, e.g. between Detroit and Chicago airports, would be combined with a flight (private communication, Larry R. Johnson). An energy-efficient lightweight vehicle and guideway might be enabled by magnetic levitation. Such vehicles might be able to operate along expressway rights of way.

The energy implications of such developments are of course quite uncertain. Nevertheless, we know that the technological ferment of our times is counterbalanced by the capital-intensity of transportation, including not only the equipment directly involved, but the equipment of suppliers including, especially, energy suppliers. Moreover, inertia is created not only by physical capital but also by human capital, our organizations, modes of operation, and knowledge. This suggests that although modifications of existing systems can be achieved in relatively short times (such as the improvement of in-use automotive fuel economy and the increase of the average passenger capacity per airplane of commercial airlines since the early 1970s), more profound changes will take longer. They will take longer especially if they are motivated by concerns other than improvement in the service provided.

CONCLUSIONS

This wide-ranging discussion was intended as an antidote to the concept of autonomous energy demand, i.e. the concept that demand is not subject to ordinary policy making the way supply is. Even without considering modal switching or alternative fuels, there is great uncertainty in the energy requirements for transportation. Moreover, that uncertainty is not only associated with hard-to-control factors such as the world oil price and consumer tastes, it also depends sensitively on the energy-efficiencies of the technologies used. These technologies will, in turn, depend on what the manufacturers choose to develop and market and on public policies. There are public policies, with which we already have experience, that (in the author's opinion) are not economically severe and that do not severely intrude on private decision-making, that would probably have powerful impacts on transportation technologies and energy use during the first decade of the next century.

An exercise by the author to quantify the uncertainty in personal-passenger-vehicle energy use in 2010 yielded high and low scenarios, with energy use in the high scenario twice as high as in the low scenario. These diverse outcomes are the result of moderate, unsurprising developments and choices. The point is that energy demand is, to a critical degree, a matter for rational decisionmaking, rather than simply being an act of God or the consequence of a particular fuel-price elasticity—if one looks ahead far enough in the future so

that there is time to make decisions (at normal replacement times) about the capital equipment involved.

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**CAFE OR PRICE?:
An Analysis of the Effects of Federal Fuel
Economy Regulations and Gasoline Price on New Car MPG,
1978-89**

*David L. Greene**

Following a tripling of world oil prices in 1973-74, the U.S. Congress passed the Energy Policy and Conservation Act of 1975 establishing mandatory fuel economy standards for automobiles and light trucks. Beginning at 18 MPG in 1978, the passenger car standards increased to 27.5 MPG by 1985. There has been considerable debate about the influence of the standards, as opposed to the gasoline price increases in 1973-74 and 1979-80, on new car fuel economy. Twelve years of average fuel economy data are now available for every manufacturer's domestic and imported car fleets, making possible a statistical estimation of the relative importance of standards versus fuel prices in determining new car MPG. In this paper a penalty function is formulated in which deviations from either the standard or the market equilibrium demand for fuel economy create costs for manufacturers. An equation for new car MPG is derived by minimizing the sum of quadratic penalty functions. Estimation of the model, using 15 sets of manufacturer CAFE data for 1978-89, clearly indicates that the CAFE standards were a significant constraint for many manufacturers, and were perhaps twice as important an influence as gasoline prices. A test for structural change in the model does not reject the hypothesis that the CAFE constraint had the same effect on carmakers before and after 1983.

INTRODUCTION

In 1974 the fuel economy of new U.S. passenger cars hit its lowest point in recent history: 14 miles per gallon (MPG) (Heavenrich, et al., 1984). At the same time, the Organization of Petroleum Exporting Countries exercised its new found market power by tripling world oil prices. The oil price shock, together with an oil embargo of the United States organized by

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the Arab members of OPEC and regulation of petroleum prices within the U.S., caused gasoline supply shortages and waiting lines at gas pumps. One response to these events was the passage of the Energy Policy and Conservation Act (EPCA) of 1975 (PL 94-163), which required manufacturers to meet fuel economy targets, beginning at 18 MPG in 1978 and increasing to 27.5 MPG by 1985. Efficiency targets were also specified for light trucks. Compliance is measured by the corporate average fuel economy (CAFE) number, which is the salesweighted harmonic mean MPG of a manufacturer's products. The targets must be met for domestic and imported fleets individually or a substantial fine, \$5 per car sold per 0.1 MPG of shortfall, must be paid. By exceeding the standards in some years manufacturers may offset shortfalls in other years without penalty. The intent of the automotive fuel economy standards (AFES) was to stimulate technological improvements that would increase efficiency without substantially altering the size distribution of vehicles sold (U.S.DOT, NHTSA, 1977).

By 1988, new car efficiency doubled, exceeding 28 mpg (Figure 1). Cars became about 25% lighter but maintained their interior size and carrying capacity. Horsepower to weight ratios increased despite the reduction of engine size by more than one third (Heavenrich and Murrell, 1988). More efficient technologies, such as front wheel drive and fuel injection, all but totally replaced their less energy efficient counterparts. The transition appears to have been accomplished without compromising consumer satisfaction (Greene and Liu, 1989). The direct fuel cost savings to American consumers has been put at one quarter of a trillion dollars through 1987 (Greene, Sperling, and McNutt, 1989).

Since gasoline prices increased and the standards were enacted at about the same time, the relative importance of the regulations versus the market response to higher prices is not obvious. Some have argued that the MPG improvements are the natural response of the marketplace to rising fuel prices and that the AFES have had little effect (e.g., Crandall et al., 1986), while others have claimed that the market is inherently unlikely to respond strongly to gasoline price changes (von Hippel, 1987). Those holding the former view conclude that any externalities associated with petroleum consumption are most efficiently dealt with by means of a tax on oil, not fuel economy regulation. Those who doubt the efficacy of the market argue that technology is what improves energy efficiency and that regulation is a more effective way of bringing about technical efficiency improvements. The extent to which the fuel economy standards, as opposed to gasoline prices, brought about higher efficiency is of more than academic interest because it bears on the need for, and likely effectiveness of, future fuel economy regulation.

This paper describes a statistical test of the importance of the CAFE constraint, using individual manufacturer CAFE data compiled by the National Highway Traffic Safety Administration (NHTSA) for the period 1978-89 (U.S.DOT, NHTSA, 1989). Some manufacturers, particularly Japanese manufacturers, consistently exceeded even the 1985 standard of 27.5 MPG. The existence of manufacturers for whom CAFE was no constraint, as well as

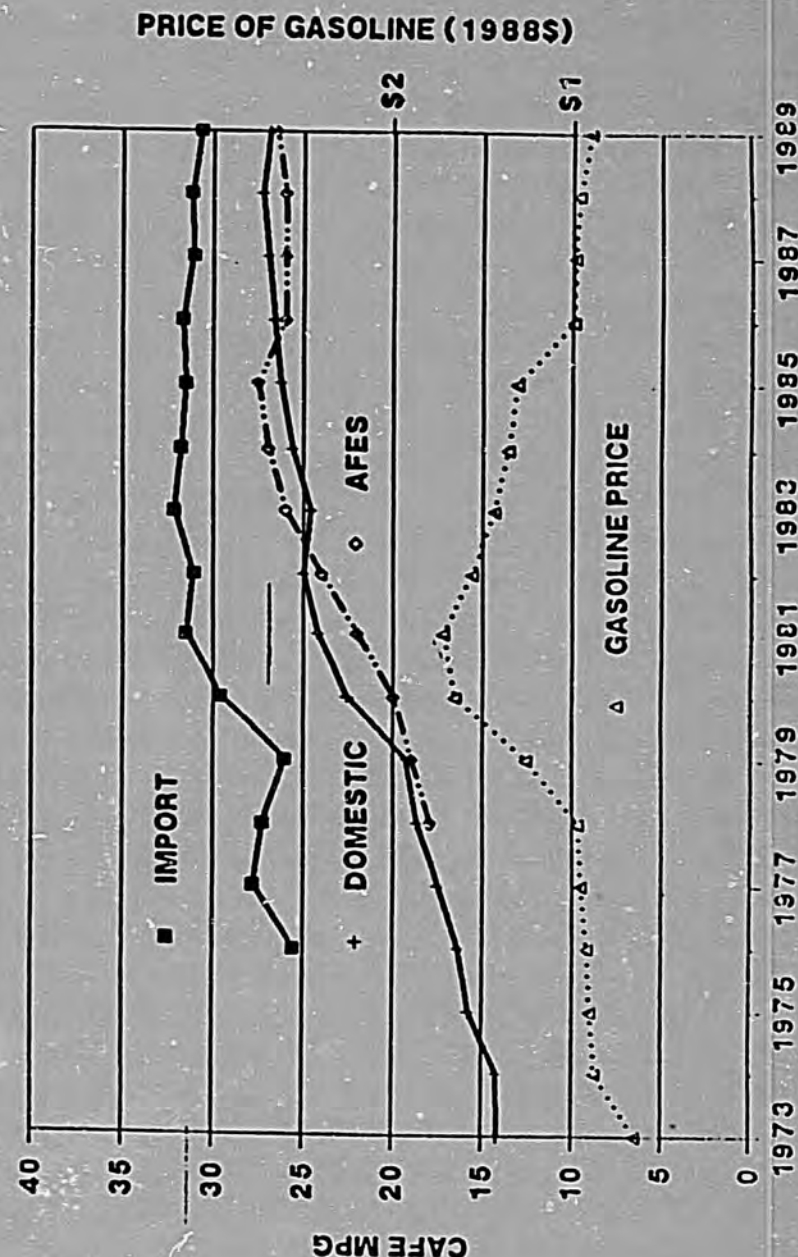


Figure 1. Trends in Fuel Price and Auto MPG, 1973-1989

those for whom it may have been a significant constraint, can be used to help discriminate between price and regulatory effects. The goals of this analysis are (1) to quantify the importance of EPCA regulations relative to gasoline prices in manufacturer decision-making about new car fuel economy, and (2) to derive an estimate of the responsiveness of new car fuel economy to gasoline price in the absence of a fuel economy constraint.

MANUFACTURER DECISION-MAKING WITH A FUEL ECONOMY CONSTRAINT

In the presence of government fuel economy regulation, the manufacturer faces the problem of balancing the need to comply with the law against the need to provide the level of fuel economy and other vehicle characteristics that the market demands. As fuel prices fluctuate, market demand for fuel efficiency should rise and fall. The federal standards may be consistent with or contrary to these market trends. Nonetheless, the automobile manufacturer must be concerned with both. Just as there are fines for failure to meet the standards, the penalty of lost profits and lost market share must be paid for being out of step with the market.

Assume that the manufacturer's objective in selecting a level of fuel economy, E , is to minimize the combined penalties of being out of step with the level of fuel economy that would maximize his profits in the absence of regulation, E_M , and the level required by regulation, E_R .

$$\text{Minimize } Z = f(E_M, E) + dg(E_R - E) \quad (1)$$

$$d = \begin{cases} 0 & \text{if } E \geq E_R \\ 1 & \text{if } E < E_R \end{cases}$$

The regulatory penalty is a linear function of the difference between the MPG achieved by the manufacturer and the automotive fuel economy standard: \$5 per 0.1 MPG per vehicle sold. In reality, however, the situation is more complicated. There are nonmonetary penalties as well: bad publicity and personal liability for the company's management. Furthermore, manufacturers can use credits earned by exceeding the standards in some years to offset deficits in others. Finally, they have the option of pressing for a rulemaking to lower the standard. This strategy was successful in lowering the AFES by 1 MPG or more in each of the years from 1986-89.

The penalty for being out of step with the market will depend not only on the cost of producing efficiency but also on the trade-offs between efficiency and other valued vehicle attributes and the ability of manufacturers to advance technology and change the trade-offs, as well as on input prices and consumers' preferences. Since the regulatory penalty should not affect any of these factors, it is reasonable to assume that the penalty functions are

additive, as shown in equation (1). As a second-order approximation to more complex penalty functions, f and g are assumed to be quadratic functions of the differences between the desired market (or regulatory) levels and the efficiency actually achieved.

A quadratic approximation to the manufacturer's penalty function might seem inappropriate at first.¹ The statutory penalties associated with the federal fuel economy regulations are \$5 per tenth of an MPG by which the manufacturer falls short of the standard multiplied by the number of cars sold, and zero if the standard is exceeded. Thus, it would appear that the penalty function is piecewise linear and that there is no benefit at all to exceeding the standard. However, manufacturers must plan years in advance to achieve future fuel economy goals in a future market in which fuel prices, consumer preferences and competition are uncertain. The importance of this fact to understanding the role of fuel economy regulation cannot be overemphasized. Thus, there is an insurance benefit to manufacturers in planning to exceed the standards. Furthermore, the CAFE law allows manufacturers to build up credits by exceeding the standards which can be used to offset deficits in other years. This carry forward-carry back provision, together with the uncertainty manufacturers face in planning for future MPG, requires that the penalty function allow benefits for exceeding the standards as well as costs for falling short. It is also clear that the true form of the penalty function is unknown. In light of the above, the quadratic approximation is a reasonable one.

An equation for E can be derived from the first-order conditions for minimizing Z with respect to E , by solving for E .

$$\begin{aligned} dZ/dE &= d/dE \{ [a + b(E_M - E) + c(E_M - E)^2] + d[\alpha + \beta(E_R - E) + \tau(E_R - E)^2] \} \\ &= -b - 2c(E_M - E) - d\beta - 2d\tau(E_R - E) = 0. \end{aligned}$$

Solving for E gives,

$$E = (b + \beta)/2(c + \tau) + [c/(c + \tau)]E_M + [\tau/(c + \tau)]E_R, \text{ if } d = 1 \quad (2)$$

$$= b/2c + E_M, \text{ if } d = 0 \quad (2a)$$

or,

$$E = A + (1 - B)E_M + BE_R, \text{ if } d = 1, \quad (2b)$$

where $A = (b + \beta)/2(c + \tau)$ and $B = (\tau/(c + \tau))$.

Thus, for these simple but flexible penalty functions, the optimal new car fuel economy will be a weighted average of the optimal market level of MPG and

1. I am grateful to Jim Sweeney for his comments and insights on this point.

the CAFE requirement, when the CAFE constraint is binding, but simply a function of the market's desired fuel economy when the AFES are not binding. Equation (2) also shows that the more important the regulatory constraint is, the less important the market's desired MPG level.

Assume that the market level of fuel economy is a function of current, year t , and past gasoline prices up to a maximum lag of L years.

$$E_M = E(p_t, p_{t-1}, \dots, p_{t-L}). \quad (3)$$

In reality, E_M depends on many factors besides fuel price, but fuel price should be by far the most important factor. According to recent research, consumers form their expectations about future gasoline prices based on experience within the last three months as well as trends over the last sixteen months (EEA, Inc., 1983). Thus, L should be at least 2 to account for consumers' desired fuel economy level. The market desired fuel economy level will also depend on the types and characteristics of vehicles manufacturers produce. Manufacturers can do very little to change the technology of their product offerings (they are basically limited to pricing strategies) with less than two years advance notice. Therefore, L should be chosen based on the leadtime required for manufacturers to make significant changes in product lines. New carlines or engines require four to five years leadtime, while significant redesign of existing makes and models may require up to three years advance preparation (EEA, Inc., 1981; Ford, 1984). Thus, $L=5$ (six time periods) should be adequate to estimate a model combining manufacturers' and consumers' price expectations.

It is important to allow the data to determine the best form of the market efficiency equation (3). A reasonably flexible model is the polynomial distributed lag (PDL) model, in which the coefficients of the price expectation equation,

$$E_M(t) = b + b_0 p_t + b_1 p_{t-1} + \dots + b_L p_{t-L}, \quad (4)$$

are assumed to follow a polynomial of chosen degree (Madalla, 1988, pp. 355-361). If the polynomial is quadratic, for example, then,

$$b_i = a_0 + a_1 i + a_2 i^2. \quad (5)$$

(The a 's and b 's here are unrelated to those in equations (1) and (2).)

Because the lagged variables are highly correlated, equations (4) and (5) are most effectively estimated by using a smaller number of variables constructed from the p_{t-i} 's. Using equation (5), we can express $E_M(t)$ in terms of the quadratic equation coefficients,

$$E_M(t) = b + \sum_{i=0}^L (a_0 + a_1 i + a_2 i^2) p_{t-i}$$

↓
 p_{t-i}

$$= b + a_0 z_{0t} + a_1 z_{1t} + a_2 z_{2t} \quad (6)$$

where the z 's are defined by,

$$z_{0t} = \sum_{i=0}^L p_{t-i}, \quad z_{1t} = \sum_{i=0}^L i p_{t-i}, \quad z_{2t} = \sum_{i=0}^L i^2 p_{t-i} \quad (7)$$

The lagged price coefficients, b_i , can then be calculated from the coefficients of the z_k using equation (5). The PDL model cannot represent all plausible price expectation models. However, it does allow the data to determine the way expectations are formed, given that fixed weights must be used.

Some manufacturers, especially Japanese manufacturers, were consistently well above the AFES requirements. In this study, any manufacturer who in year t is consistently more than one M' above the AFES for year $t+3$ is considered to be unconstrained (equation 2(a) applies). For example, in 1978 the AFES was 18 MPG, and the 1981 AFES was 22 MPG. A manufacturer with a CAFE of more than 23 MPG in 1978 would be considered unconstrained in that year. If the regulatory standard is not a constraint (its penalty function is zero), the optimal level of fuel economy is the market level, E_M , plus a constant. The constant may be interpreted as a given manufacturer's deviation from the market average fuel economy and may thereby reflect a manufacturer's specialization in particular market segments.

The efficiency equation to be estimated is, therefore,

$$E_m(t) = A_m + (1-d_m B) E_M(t) + d_m B E_R(t), \quad (8)$$

where,

$$d_m = \begin{cases} 0 & \text{if manufacturer } m \text{ is unconstrained and,} \\ 1 & \text{if manufacturer } m \text{ is constrained by the AFES,} \end{cases}$$

and A_m is a manufacturer-specific intercept.

Substituting equation (6) into equation (8) we get the form of the model used for estimation.

$$E_m(t) = A_m + (1-d_m B)(b_0 + a_0 z_{0t} + a_1 z_{1t} + a_2 z_{2t}) + d_m B E_R \quad (9)$$

$$= A_m + b_0^i + a_0^i z_{0t} + a_1^i z_{1t} + a_2^i z_{2t} + d_m B E_R$$

The superscript, i , indicates that coefficients are different for constrained

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versus unconstrained manufacturers. Assuming identical E_M functions, the coefficients should differ by a constant factor, $(1-B)$. In the estimation we do not impose this constraint, which allows constrained and unconstrained manufacturers to have different functions. This produces an interesting result, as will be seen.

The PDL formulation allows the data to dictate how past fuel prices influence new car fuel economy. Because of manufacturers' leadtime requirements, we can expect the current year and one-year lag coefficients to reflect the response of consumer demand to gasoline price changes, while longer lags reflect the manufacturers' response via new and redesigned product offerings. Current and one-year lags may also reflect manufacturers' short-term reaction to changes in the market demand for fuel economy (e.g., pricing strategies to encourage sales of more efficient car types). For the fuel economy standard, only the current year is included since the standards are generally set far enough in advance to allow manufacturers time to adjust their product offerings. Exceptions are the rulemakings in 1986-1989, which lowered the AFES on relatively short notice.

FUEL ECONOMY AND FUEL PRICE TRENDS

The general trend of automobile MPG over the past fifteen years suggests a strong relationship to the fuel economy standards. Gasoline prices rose sharply twice, declined gradually twice, and fell sharply once (Figure 1). The 1989 price of \$0.96 (1988 \$s) is actually below the constant dollar price in 1975. At the same time, domestic automobile MPG doubled from 14 to 28 MPG, increasing in every year except 1983. The efficiency of imported cars also increased, though less dramatically (Figure 1). These gasoline price and MPG trends certainly suggest a correlation between the fuel economy standards and the fuel economy realized, in particular, by domestic manufacturers. A closer look at individual manufacturers' CAFE numbers reveals at least three different types of patterns (NHTSA, 1989).

The CAFE MPG of the "Big Three" domestic manufacturers (Chrysler, Ford, and General Motors) are very close to the AFES in every year (Figure 2). Each experienced a decline in fuel economy in 1983; GM and Chrysler also expect declines in 1989; Ford's CAFE slipped in 1987 and 1988. Only Chrysler consistently exceed the AFES of every year, but all three manufacturers satisfied the EPCA regulations by using credits earned by exceeding the standards some years to offset shortfalls in others (Automotive News, 1989). Certain European manufacturers' CAFE numbers exhibit the same "constrained" pattern (e.g., Volvo, Figure 3).

Other imported manufacturers were far above the 18 MPG standard in 1978 and remained well above the AFES throughout the twelve-year period (see Figure 3). For example, Volkswagen's salesweighted MPG was in excess of 27 MPG in 1978. Most of the others who fit the "unconstrained" pattern are Japanese car builders (e.g., Toyota, Nissan).

Figure 2: Corporate Average, MPG vs. Standard – Domestic Vehicles

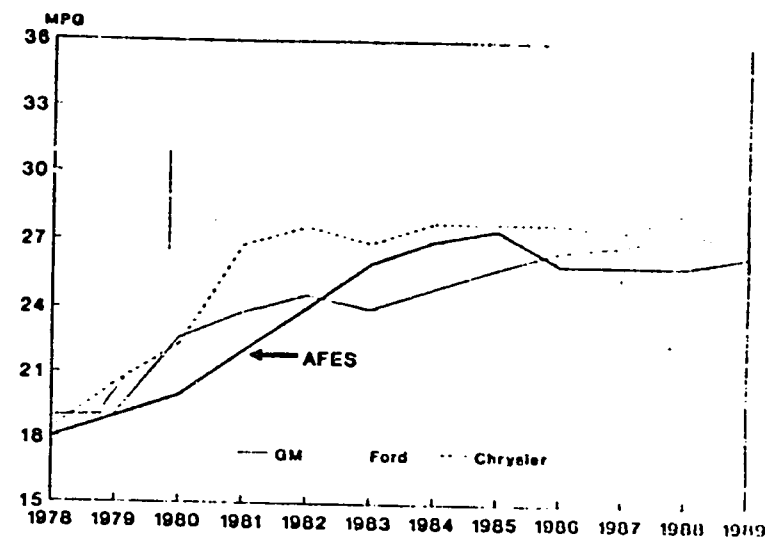
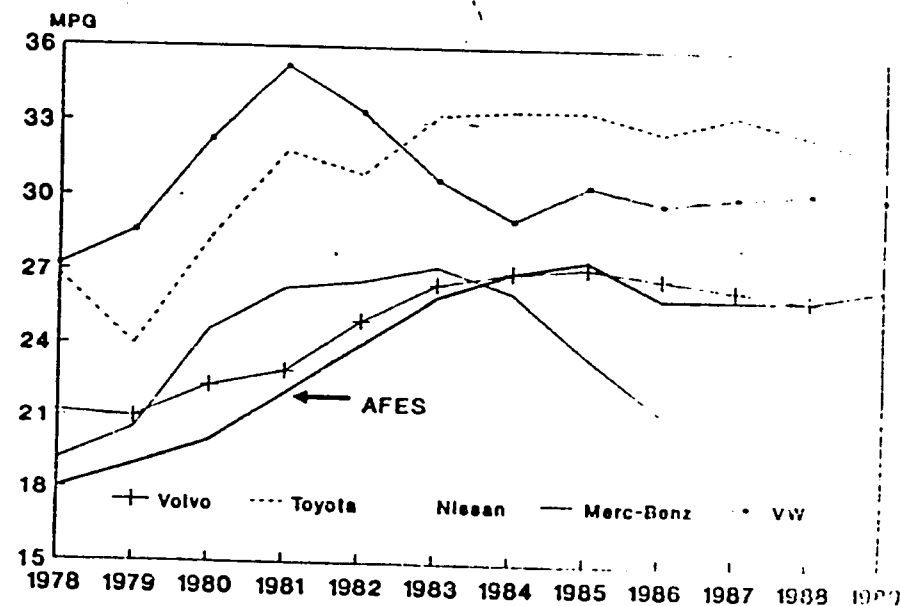


Figure 3: Corporate Average, MPG vs. Standard – Imported Vehicles



Still other importers reflect a mixed pattern. Mercedes-Benz, for example, closely followed the AFES and even exceeded them by a comfortable margin until 1984. At that point the company appears to have given up trying to meet the standard, and returned to a level of fuel economy it considered more consistent with consumer demand. Mercedes-Benz paid a \$20.2 million penalty for the 1986 model year and is reportedly facing a similar fine for 1987 (Automotive News, 1989). BMW's MPG history is similar to that of Mercedes. The fact that the two manufacturers conforming to this "discouraged" pattern both sell high-priced automobiles suggests that their market segment may be less interested in fuel economy, and less sensitive to cost, than the market as a whole.

The patterns of MPG change exhibited by the "constrained," "unconstrained," and "discouraged" examples, shown in Figures 2 and 3, are typical of others. In them we see graphical evidence that the AFES do matter to producers, but also that market factors matter as well. The oil price collapse in 1986 is almost certainly a factor in Mercedes-Benz' steep drop in MPG and is probably a factor in the smaller declines experienced by other manufacturers. In the following section, these tendencies are quantified by estimating the parameters of the manufacturers' MPG decision model specified above.

The principal source of data for this analysis is the National Highway Traffic Safety Administration's official CAFE estimates (U.S. D.O.T., 1989). NHTSA compiles data for every manufacturer's domestic and imported fleet, and for light trucks as well as cars. Only the passenger car data were used in this study. Only manufacturers with a full twelve years of CAFE numbers were included. In addition, Ford's imported car line was dropped because of the lack of stability in product offerings. Until 1985 Ford imports sold only the Ford Fiesta. This changed drastically in 1985 when the Fiesta was dropped, and drastically again in 1988 when the Ford Festiva was introduced. Low-volume, high-performance, high-priced luxury cars were also excluded. This category included Alfa-Romeo, Jaguar, and Rolls-Royce (similar manufacturers, such as Ferrari and Lamborghini, did not have a full twelve years of data). The fifteen manufacturers included were: BMW, Chrysler domestic, Chrysler import, Ford domestic, GM domestic, Honda, Mazda, Mercedes-Benz, Nissan, Peugeot, Saab, Subaru, Toyota, Volvo, and Volkswagen.

Fuel price data for 1973-1989 were obtained from the Monthly Energy Review and Annual Energy Review (U.S. D.O.E., 1988, 1989). Prior to 1978 the average price of regular leaded gasoline was used because the series for the average price of all grades begins in 1978 and because the price series for unleaded regular does not begin until 1976. In 1978 and subsequent years the average of all grades was substituted. While most new cars are designed for unleaded regular, many owners buy premium, and a significant number misfuel with leaded gasoline. In any case, all of the DOE gasoline price series are highly correlated. Prices were inflated to 1988 dollars using the implicit price deflator of the Gross National Product.

THE IMPORTANCE OF MPG STANDARDS: ESTIMATION AND INFERENCE

In this section the parameters of the manufacturer's efficiency equation are estimated and several hypotheses about the structure of the equation and its stability over time are tested. First, equation (8) is estimated to determine the relative importance of fuel prices and fuel economy regulations and to infer the nature of manufacturers' responses to gasoline price increases. Next the stability of the price effect during periods of falling versus rising prices is tested. The stability of the effect of the fuel economy constraint over time is also subjected to a statistical test. Next a model is tested that implies that, given the AFES, fuel prices may have been irrelevant to the product planning of constrained manufacturers. Finally, inferences about the price elasticity of MPG are presented for unconstrained carmakers, and for the short-run effect on constrained manufacturers.

The parameters of the manufacturers' efficiency decision model (equation 8) were estimated using the least squares dummy variable (LSDV) method on the time series of cross-sectional manufacturer data. A dummy variable was included for each of the fifteen manufacturers. Ordinary least squares was the estimation technique and manufacturer data were not weighted by sales volume. Thus, Mercedes-Benz gets just as much weight as General Motors in the determination of model parameters. The LIMDEP (TM) econometric software package performed the calculations (Greene, 1986).

Results for the basic PDL model indicate that, for constrained manufacturers, the weight given the AFES is roughly twice that given the market-determined level of MPG (Table 1). The coefficient of F_R is 0.72, which implies that the market MPG weight is 0.28. In a previous study, Santini and Vyas (1988) regressed the change in average MPG for all new cars against the change in CAFE, a trend variable, and two price variables, and obtained a coefficient for the change in CAFE of 0.354. Given the differences in model formulation and data, the two results are not inconsistent. Most of the constructed price variables are statistically significant at the 0.05 level. An F test for all of the price variables proved that their combined effect is easily significant at the 0.01 level. The overall fit of the model to the data is reasonably good: the adjusted R^2 was 0.79.

Pattern of Response to Price Changes

The pattern of lagged price response can be computed from the coefficients of the constructed price variables in Table 1. Lagged price coefficients for the unconstrained manufacturers can be computed directly from the coefficients of z_0 , z_1 , and z_2 in Table 1, by using equation (5). Those for the constrained manufacturers are computed from the coefficients $z_0 + z_0 d_m$, $z_1 + z_1 d_m$, and $z_2 + z_2 d_m$ respectively, and dividing each by $(1-0.72)$.

Table 1. PDL Model Estimates

Variable	Coefficient	Std. Error	t-ratio	Signif. Level
Dummy variables				
BMW	5.20	2.72	1.91	0.055
Chrysler D	6.34	2.72	2.33	0.020
Chrysler I	26.94	2.43	11.08	0.000
Ford D	4.97	2.72	1.83	0.066
GM D	4.86	2.72	1.79	0.072
Honda	26.43	2.43	10.87	0.000
Mazda	23.28	2.43	9.57	0.000
Merz-Benz	3.91	2.72	1.43	0.149
Nissan	23.98	2.43	9.86	0.000
Peugeot	6.11	2.72	2.24	0.025
Saab	5.71	2.72	2.10	0.036
Subaru	24.95	2.43	10.26	0.000
Toyota	24.60	2.43	10.12	0.000
Volvo	5.32	2.72	1.95	0.050
Volkswagen	24.17	2.43	9.94	0.000
z_0	-0.925	0.715	-1.29	0.195
z_1	1.910	0.864	2.21	0.027
z_2	-0.361	0.178	-1.91	0.054
z_0^d	3.595	1.052	3.42	0.001
z_1^d	-4.035	1.239	-3.26	0.001
z_2^d	0.660	0.249	2.65	0.007
AFES, E_{Rd_m}	0.719	0.085	8.43	0.000

Adjusted $R^2 = 0.785$

Mean of Dependent Variable = 27.83

Std. Err. of Regression = 1.94

Std. Err. Dep. Var. = 4.19

The division by $(1-0.72)$ removes the assumed penalty function weight of $(1-B)$ on the market MPG equation. In accordance with equation (8), this is necessary to obtain the price responsiveness in the absence of the AFES regulations. In the penalty function, the market-determined fuel economy level receives a weight of $(1-0.72)=0.28$, so that its potential effect on new car efficiency is muted. Results presented below, however, indicate that rescaling (increasing) the constrained-car-maker price coefficients is not entirely appropriate.

Initially, one might expect the market efficiency equations for constrained and unconstrained manufacturers to be essentially the same. In fact, the estimated coefficients imply very different responses by constrained and unconstrained manufacturers to changes in the price of gasoline. According to the lagged price coefficients (Figure 4), the new car MPG of unconstrained manufacturers is determined by fuel prices of two to four years ago. This is consistent with what we know about necessary leadtimes for product development (e.g., Ford, 1984). In sharp contrast, the response of manufacturers constrained by the AFES is nearly all in the current year.

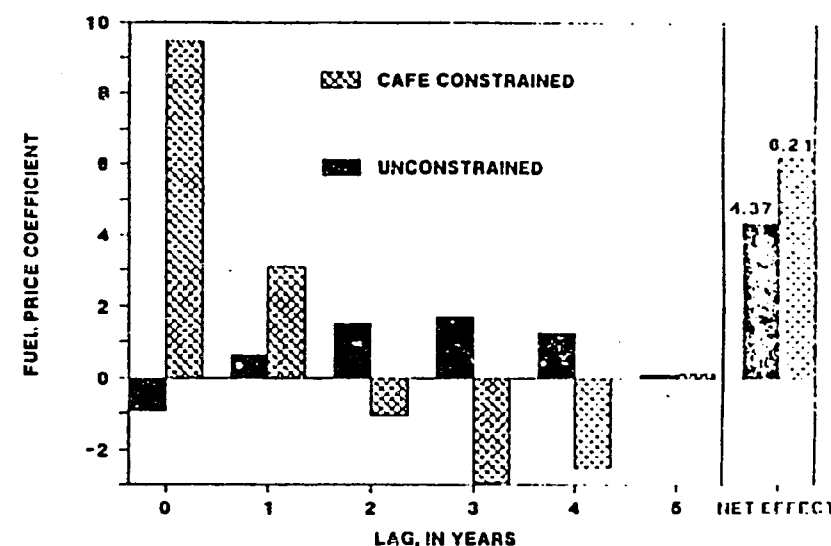


Figure 4. Lag Structure of Response to Fuel Price
(by Manufacturer Relation to CAFE Constraint)

For the constrained manufacturers, product planning has been dominated by the requirement to meet the AFES goals. Thus, the potential impact of past fuel prices on research and design has been overwhelmed by planning to meet the fuel economy goals required by law. For the unconstrained manufacturers this is not the case, and their product planning has been guided by their expectations of the level of fuel economy the market would require two to four years hence.² If the above argument is correct, it implies that $B=1$ and the level of MPC preferred by the market have not been factors in the long-run product planning of AFES-constrained car manufacturers. This

2. In fact, to some degree the fuel economy standards appear to have been a constraint on the "unconstrained" manufacturers as well. Estimations of the PDL model, as well as a simpler form discussed below, including a fuel economy standard variable for unconstrained manufacturers, produced statistically significant coefficients for that variable which were one-third to one-half the size of the CAFE constraint coefficients for "constrained" manufacturers. Other coefficients are affected very little by the inclusion of the CAFE constraint variable for "unconstrained" manufacturers. Results are available from the author. Although the federal fuel economy standards appear to have had some influence even on "unconstrained" manufacturers, the strict unconstrained definition is maintained in this paper. Strictly speaking, "unconstrained" is more properly interpreted as "mostly unconstrained" or "much less constrained." The author is grateful to Jim Sweeney for suggesting the investigation of this issue.

hypothesis is tested below and is not rejected. This, however, does not explain the lack of significance of current-year prices to unconstrained manufacturers.

Responsiveness to current year prices cannot come about by changing the engineering, design, or technology of product offerings. It is too late for such actions. It must be due to changes in the sales distribution, given the makes and models available. Thus, it must represent a consumer response, more than a manufacturer decision. In effect, it is outside of the manufacturer decision-making model presented above. When fuel prices rise, car buyers look for more efficient makes and models, raising the full-line manufacturers' average fuel economy. The constrained manufacturers' sales distributions are affected because they tend to sell a wide range of cars with differing efficiencies. The unconstrained carmakers, on the other hand, tend to sell a more limited line of efficient cars. Though they may gain market share when the current price of fuel jumps, it apparently has little effect on their sales distribution or average MPG.

The patterns of price response illustrated in Figure 4, and the above line of reasoning, suggest that a simpler formulation of the price variables may be adequate: for constrained carmakers include only the current year fuel price (P) and for unconstrained carmakers use the simple average of prices two, three, and four years ago (P2-4). Results for this simpler formulation are shown in Table 2. This formulation, which fits the data nearly as well as the complete PDL model, is more convenient for testing certain hypotheses about price effects.

Table 2. Estimated Coefficients of Simplified Model (Dummy variables omitted from table for brevity)

Variable	Coefficient	Std. Error	t-ratio	Signf. Level
P	-0.667	0.669	-1.00	0.322
PB	4.049	1.065	3.80	0.000
P2-4	4.790	1.088	4.40	0.000
P2-4 _u	-6.324	1.618	-3.91	0.000
AFES	0.728	0.086	8.49	0.000

Adj. R² = 0.783 Std. Err. of Regression = 1.95

Test of Linear Restrictions, P = 0, P2-4 - P2-4_u = 0
F (2, 160) = 1.318, Signf. Level = 0.270

PB	2.851	0.717	3.98	0.000
P2-4	4.527	1.056	4.29	0.000
P2-4 _u	-4.527	1.056	-4.29	0.000
AFES	0.670	0.073	9.18	0.000

Adj. R² = 0.782 Std. Err. of Regression = 1.96

Stability of Price Effects

One might expect rising prices to have a different effect on new car MPG than falling prices for two reasons. First, if rising prices stimulate technological change, fuel economy will not return to its original level when price falls back to its original level. If technology has truly advanced, we would return to a somewhat higher level of MPG because better technology means we can have more MPG and more of everything else we want in a car at the same time (there is considerable empirical evidence that fuel economy technology has advanced -- see Greene, 1987; EEA, Inc., 1986; U.S. DOT, NHTSA, 1982). Thus the price coefficient for periods of rising prices would be greater than that for falling prices. Second, manufacturers can influence the salesmix in the short run by offering incentives or changing the prices of makes and models, e.g. as Kwoka (1983) has argued. But they would most likely try to shift sales only when prices were falling, to counteract the downward pressure on MPG so as to still meet the AFES targets. The effect of this would be to dampen the market response when prices are falling. Once again the coefficient for rising prices should be greater than that for falling prices.

Figure 1 suggests that the 1973 to 1989 period can be roughly divided into two parts: a period of generally increasing prices from 1973 to 1981, and a period of generally decreasing prices from 1982 to 1989. If we allow for a two-year lag for expectations to change, we have a period of rising prices from 1973-82, and falling prices afterwards. A test of price responsiveness for these two periods does indicate different modes of response. The current-year price response for domestic manufacturers appears to be about twice as large during the period of rising prices (2.5 vs. 1.2, Table 3). For unconstrained manufacturers the price coefficients are much closer in value (3.4 vs. 4.1) but there is a statistically significant increase in price sensitivity for the post 1982 period. Recall that these are predominantly Japanese manufacturers of efficient automobiles. It appears that they may have reduced their MPG in response to falling prices in the 1980s more than they increased it in response to rising prices of the 1970s. If the intent of the EPCA was to bring about roughly equal improvements by all manufacturers, this is a disturbing result. It suggests that "market slackness" created when the AFES kept constrained carmakers from fully following market trends was taken up by the unconstrained carmakers, who took the opportunity to sell a mix of less efficient cars than they otherwise would have. This evidence lends some support to Kleit's (1987) assertion that fuel economy regulations create economies of scope that encourage all manufacturers to become full-line manufacturers.

Table 3. Test of Equality of Price Coefficients, 1978-1982, and 1983-1989
(Dummy variables omitted from table)

Variable	Coefficient	Std. Error	t-ratio	Signif. Level
PB	2.506	0.729	3.44	0.001
PB,83	-1.281	0.701	-1.83	0.066
P2-4	3.391	1.148	2.95	0.004
P2-4,83	0.701	0.304	2.30	0.021
AFES	0.857	0.125	6.86	0.000
Adj. R ² = .790 Std. Err. of Regression = 1.92				

Stability of the AFES Constraint Effect

It has been suggested that,

"The CAFE standards appear to have provided little but nuisance value until recently. As gasoline prices have fallen in real terms, the standards have become a binding constraint upon producers attempting to satisfy the demand for larger cars." (Crandall, et al., 1986, p. 139)

A look at Figure 1 shows that real gasoline prices stabilized in 1981 and began falling in 1982. If it is true that consumers base their price expectations on what has occurred in the past year and a half, by 1983 they should have decided that prices were headed downward. A Chow test was performed to evaluate the hypothesis that the effect of the CAFE standards in 1982 and before differed from their effect in 1983 and afterwards. The more flexible PDL model was re-estimated with separate AFES coefficients for the two time periods. As before, the AFES applies only to constrained manufacturers.

Not only can we not reject the hypothesis of equal effects before and after 1983, but the independently estimated coefficients are nearly exactly the same: 0.77 for pre-1983, and 0.75 for 1983 and after (Table 4). The F statistic for the null hypothesis that the two coefficients are identical is $F = 0.124$ with (1, 157) degrees of freedom, which has a significance level of 0.72. There is no evidence here to support the assertion that the automotive fuel economy standards were not binding on manufacturers prior to 1983. On the contrary, it appears that their effect has been strong and consistent throughout the entire period.

Table 4. Test of Equality of AFES Coefficients, 1978-1982 and 1983-1989
(Dummy variables omitted from table)

Variable	Coefficient	Std. Error	t-ratio	Signif. Level
z_0	-0.925	0.717	-1.29	0.196
z_1	1.910	0.866	2.205	0.027
z_2	-0.341	0.178	-1.91	0.055
$z_0^{d_m}$	3.334	1.290	2.57	0.010
$z_1^{d_m}$	-3.846	1.354	-2.84	0.005
$z_2^{d_m}$	0.635	0.260	2.44	0.015
AFES<83	0.770	0.168	4.57	0.000
AFES>82	0.749	0.122	6.13	0.000
Adj. R ² = .784 Std. Err. of Regression = 1.95				

Test of Equality of AFES Coefficients
 $F(1, 157) = 0.124$ Significance Level = 0.724

Variable	Coefficient	Std. Error	t-ratio	Signif. Level
z_0	-0.925	0.717	-1.29	0.196
z_1	1.910	0.866	2.205	0.027
z_2	-0.341	0.178	-1.91	0.055
$z_0^{d_m}$	3.595	1.055	3.41	0.001
$z_1^{d_m}$	-4.035	1.242	-3.25	0.002
$z_2^{d_m}$	0.660	0.250	2.64	0.007
AFES<83	0.719	0.086	8.40	0.000
AFES>83	0.719	0.086	8.40	0.000
Adj. R ² = 0.785 Std. Err. of Regression = 1.94				

Dominance of the AFES over Fuel Prices

If the MPG of CAFE-constrained carmakers responds only to current year fuel prices, then the coefficients of their PDL price variables should be zero and the coefficient of the fuel economy standard variable, E_R , should equal 1. We now test this hypothesis, taking into account the different response of constrained carmakers to prices during the 1978-82 and 1983-89 periods. In the results presented in Table 5 the z_i -variables are defined as in equation (5) for unconstrained carmakers, and are zero otherwise. The $z_i^{d_m}$ variables represent the PDL price variables for the constrained manufacturers. Prior to imposing the price and standard constraints, none of the price variables for constrained manufacturers is statistically significant. Jointly imposing the four constraints results in $F(4, 156) = 0.553$, which has a significance level of 0.70, so that we do not reject the hypothesis that $B = 1$. The implication is that the long-range fuel economy planning of constrained manufacturers may have been entirely dominated by the CAFE standards.

Table 5. Test of Irrelevance of Gasoline Price to Constrained Manufacturer MPG (Dummy variables omitted from table)

Variable	Coefficient	Std. Error	t-ratio	Signif. Level
z_0	-0.925	0.718	-1.29	0.196
z_1	1.910	0.867	2.20	0.027
z_2	-0.341	0.179	-1.91	0.055
z_0^d	4.908	5.351	0.92	0.364
z_1^d	-3.649	4.026	-0.91	0.370
z_2^d	0.553	0.628	0.88	0.384
FB	-3.218	6.372	-0.50	0.620
PD,83	-0.215	1.335	-0.16	0.847
AFES, E_R^d	0.716	0.199	3.60	0.000
Adj. R = 0.784 Std. Err. of Regression = 1.95				
Test of Linear Restrictions $z_0^d = z_1^d = z_2^d = 0$, AFES = 1.0				
F (4, 156) = 0.553 Significance Level = 0.700				
z_0	-0.925	0.718	-1.29	0.196
z_1	1.910	0.867	2.20	0.027
z_2	-0.341	0.179	-1.91	0.055
z_0^d	0.0			
z_1^d	0.0			
z_2^d	0.0			
FB	2.575	0.738	3.49	0.001
PD,83	-1.938	0.409	-4.74	0.000
AFES, E_R^d	1.0			
Adj. R ² = 0.786 Std. Err. of Regression = 1.94				

Estimates of Price Elasticity of MPG

Overall price elasticities can be computed either from the net effect of the lagged price responses shown in Figure 4, or from the coefficients of current and average prices 2-4 years ago in the simplified model. Note that the elasticities computed for constrained manufacturers assume the existence of fuel economy standards. One could try to infer elasticities that one would obtain in the absence of regulation by dividing by (1-B), but given the effect that regulation appears to have on the nature of the price response, this would give misleading results. The average price of gasoline for the 1978-89 period was \$1.36 per gallon and the average CAFE of all the manufacturers was 27.83 MPG. Using these values to compute elasticities of MPG with respect to a step increase in gasoline price gives,

$$(6.21 \cdot 0.28) \cdot (1.36/27.83) = 0.08$$

$$2.51 \cdot (1.36/27.83) = 0.12$$

$$(2.51 - 1.28) \cdot (1.36/27.83) = 0.06$$

$$4.37 \cdot (1.36/27.83) = 0.21$$

$$3.39 \cdot (1.36/27.83) = 0.17$$

$$4.09 \cdot (1.36/27.83) = 0.20$$

constrained, PDI model
constrained, 1978-82
constrained, 1983-89

unconstrained, PDI model
unconstrained, 1978-82
unconstrained, 1983-89

The price elasticity of MPG with respect to fuel price for unconstrained manufacturers is quite small. At a long-run elasticity of 0.21, fuel prices would have to increase from \$1.36 to \$2.15 per gallon to bring about a 10% increase in MPG. The impact of current fuel prices on constrained manufacturers is larger during the 1978-82 period of generally rising prices than during the 1983-89 period when prices were falling. This is consistent with the idea that manufacturers may take actions to resist downward pressure on their CAFE when fuel prices are falling in order to avoid violating the AFES.

Unfortunately, the above estimates cannot be interpreted as the long-run and short-run gasoline price elasticities of MPG for the entire market. The two market segments (constrained and unconstrained) are quite different and appear to respond differently to price changes. We were not able to estimate a market MPG equation as a function of past fuel prices for constrained manufacturers, apparently because the AFES constraint was binding. Their inherent responsiveness in the absence of fuel economy regulation might have been greater or less than that of the unconstrained manufacturers. In addition, the model is designed to represent the fuel economy of individual manufacturers, and thus does not address the question of market MPG improvement via shifts in sales from less to more efficient manufacturers, and vice versa. Such sales shifts are an important component of the short-run gasoline price elasticity of MPG.

CONCLUSIONS

The automotive fuel economy standards (AFES) specified by the Energy Policy and Conservation Act of 1975 and rulemakings of the Department of Transportation, appear to have had a powerful effect on the product planning decisions of the manufacturers constrained by them. This includes all the "big three" domestic manufacturers and several European carmakers as well. The statistical analysis described here indicates that the standards were at least twice as important as market trends in fuel prices, and may have completely replaced fuel price trends as a basis for long-range planning about MPG. Of course, correlation is not causality. The possibility remains that the standards were such an accurate prediction of the future

behaviour of certain manufacturers that even the relatively flexible gasoline price model used here cannot fit the data as well. This must be considered highly unlikely since the AFES are at least predetermined, and because a clear causal mechanism, compliance with the law and civil penalties, exists.

Tests of the model structure indicate that the average MPG of constrained and unconstrained carmakers responded very differently to price changes over the 1973-1989 period. The unconstrained carmakers' current-year CAFE was affected by prices two to four years old. This is consistent with the leadtime required to make engineering and design changes in product offerings. However, the elasticity of MPG with respect to fuel price was relatively small: about 0.2. Constrained manufacturers' CAFE, in contrast, was affected only by current-year prices. This effect, no doubt, combines market demand changes with carmaker pricing and incentives strategies, since technological changes cannot be made instantaneously. This elasticity is even smaller: about 0.1.

The effect of gasoline price on MPG was different during the period of falling prices in the 1980s from its effect during the period of rising prices in the 1970s. Constrained-carmaker MPG was twice as sensitive to rising prices as falling prices, suggesting that manufacturers took some actions to counteract the downward pressure of falling prices in order to meet the AFES targets. Unconstrained manufacturers, in contrast, responded slightly more to falling than to rising prices. It may be that the effects of falling prices on constrained carmakers gave the unconstrained carmakers an opportunity to expand into lower MPG market segments.

However, there was no difference in the effect of the CAFE constraint during the two time periods. The estimated weights for the AFES before 1983 and after 1982 were 0.77 and 0.75, respectively. There was no statistical support for rejecting the hypothesis that the effects were identical.

A joint test of the hypotheses that: 1) past fuel prices were not a factor in determining the MPG of constrained manufacturers, and 2) the weight of the AFES is 1.0 (only the AFES matters), could not be rejected. That is, the data are not inconsistent with the hypothesis that constrained manufacturers based their MPG product planning solely on the mandated fuel economy standards.

These results support the assertion that the EPCA CAFE standards were effective in influencing many carmakers to plan for and achieve dramatic increases in new car fuel economy.

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ENERGY PRICES IN OWN CURRENCY INCLUDING TAX

AUTOMOTIVE FUELS

RETAIL

MOTIVE FUELS				1990				1991			1992	
DETAIL	UNITS	1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
<u>Leaded Premium</u>												
Czechoslovakia	C/litre	8	8	12.4	-	13.5	18	18				
Lithuania	R/litre											4
Romania	L/litre											
<u>Unleaded Premium</u>												
Czechoslovakia	C/litre		9	12.4	-	13.5	18	18				
Lithuania	R/litre											
Romania	L/litre											
<u>Leaded Regular</u>												
Czechoslovakia	C/litre											
Lithuania	R/litre											3.5
Romania	L/litre							15			45	
<u>Unleaded Regular</u>												
Czechoslovakia	C/litre											
Lithuania	R/litre											
Romania	L/litre											
<u>Diesel</u>												
Czechoslovakia	C/litre	5.5	6.5	9.8	-	9	15	15				
Lithuania	R/litre											3
Romania	L/Litre											
<u>LPG for Vehicles</u>												
Czechoslovakia	C/GJ											
Lithuania	R/GJ											1.85
Romania	L/GJ											

AUTOMOTIVE FUELS

WHOLESALE

MOTIVE FUELS		1990				1991				1992		
WHOLESALE	UNITS	1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
<u>Leaded Premium</u>												
Czechoslovakia	C/tonne	3550	2474	2476	2476	2476	2476					
Lithuania	R/tonne											2637.5
Romania	L/tonne											
<u>Unleaded Premium</u>												
Czechoslovakia	C/tonne	3550	2474	2476	2476	2476	2476					
Lithuania	R/tonne											
Romania	L/tonne											
<u>Leaded Regular</u>												
Czechoslovakia	C/tonne	3550	2474	2476	2476	2476	2476					
Lithuania	R/tonne											1857
Romania	L/tonne											
<u>Unleaded Regular</u>												
Czechoslovakia	C/tonne	3550	2474	2476	2476	2476	2476					
Lithuania	R/tonne											
Romania	L/tonne											
<u>Diesel</u>												
Czechoslovakia	C/tonne	2834	2080	2080	2080	2080	2080					
Lithuania	R/tonne											1800
Romania	L/tonne											
<u>LPG for Vehicles</u>												
Czechoslovakia	C/GJ											
Lithuania	R/tonne											1785
Romania	L/GJ											

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FUEL OIL RETAIL/RESIDENTIAL				1990				1991				1992
		1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
Light Fuel Oil	UNITS											
Czechoslovakia	C/litre	820	820	820	820	820	820					
Lithuania	R/tonne											1877
Romania	L/tonne			1875								

WHOLESALE/INDUSTRY		1990				1991				1992		
Light Fuel Oil		1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	
Czechoslovakia	C/litre	24.51	24.75	35.69	-	31.3	59.34	54.58				1785
Lithuania	R/tonne											
Romania	L/litre											
Heavy Fuel Oil		1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1992
Czechoslovakia	C/tonne	2290	1700	2718	-	2760	4710	4272				1171.5
Lithuania	R/tonne											
Romania	L/tonne		1875					1500				

PROPANE/BUTANE/KEROSENE RETAIL UNITS		1990				1991				1992		
		1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
Propane Butane Mix												
Czechoslovakia	C/GJ											
Lithuania	R/GJ											31.28
Romania	L/GJ											

LPG	UNITS											
Czechoslovakia	C/tonne	4203	4249									
Lithuania	R/tonne											
Romania	L/tonne											

Kerosine	UNITS											
Czechoslovakia	C/litre	5	5	6								
Lithuania	R/litre											
Romania	L/litre											

WHOLESALE		1990				1991				1992		
Propane Butane Mix		1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
Czechoslovakia	C/tonne											
Lithuania	R/tonne											1775
Romania	L/tonne											

LPG	UNITS											
Czechoslovakia	C/tonne	4981	3166									
Lithuania	R/tonne											
Romania	L/tonne											

Kerosine	UNITS											
Czechoslovakia	C/tonne	3325	2160	2160								
Lithuania	R/tonne											
Romania	L/tonne											

CRUDE OIL		1990				1991				1992		
WHOLESALE	UNITS	1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
Czechoslovakia	C/tonne	2250	1550	1550	1550	1550	5280					
Lithuania	R/tonne										70	
Romania	L/tonne							8000				25476

TURAL GAS INDUSTRIAL USE		UNITS	1990				1991				1992		
			1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
Czechoslovakia	C/10 ⁷ kcal	2414	1746	1777	-	1530	2520	3350					
Lithuania	R/ m ³											42	
Romania	L/tonne		1000				2800					6000	

ELECTRIC GENERATION												
Czechoslovakia	C/10 ^ 7 kcal	2414	1746	2355	-	2027	3338	4439				
Lithuania	R/t m ^ 3										42	
Romania	L/tonne		1000				2000				6000	

RESIDENTIAL USE											
Czechoslovakia	C/10 ^ 7 kcal	1080	1058	1058	-	1058	1058	1058			
Lithuania	R/t m ^ 3										3.02
Romania	L/tonne										

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COAL	UNITS	1990				1991				1992		
		1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
INDUSTRIAL USE												
Steam Coal												
Czechoslovakia	C/tonne	102	105	235	-	215	311	311	471			
Lithuania	R/tonne											
Romania	L/tonne		179					350			810	
Coking Coal												
Czechoslovakia	C/tonne	705	917	944	-	917	1320	1487	1661.1			
Lithuania	R/tonne											
Romania	L/tonne											
Coke												
Czechoslovakia	C/tonne	985.32	1314.91	1349.81	1349.81	1349.81	1349.81	1934.2				
Lithuania	R/tonne											
Romania	L/tonne											

ELECTRIC GENERATION

Steam Coal

Czechoslovakia	C/tonne	102	109	134	-	120	179	179				
Lithuania	R/tonne											
Romania	L/tonne							350			810	

RESIDENTIAL USE

Steam Coal

Czechoslovakia	C/tonne	180	180	180	-	180	180	180				
Lithuania	R/tonne											
Romania	L/tonne											

ELECTRICITY

UNITS

LIGHT INDUSTRIAL***

Consumption Charge

Czechoslovakia	C/kwh	0.488	0.477	0.525	-	0.499	0.597	0.597				
Lithuania	R/kwh											0.30
Romania	L/kwh							2.2			12.7	

Demand Charge#

Czechoslovakia	C/KW											
Lithuania	R/KW											750
Romania	L/KW									2407		

HEAVY INDUSTRIAL

Consumption Charge

Czechoslovakia	C/kwh											
Lithuania	R/kwh											0.3
Romania	L/kwh		0.57					0.8			5.7	

Demand Charge#

Czechoslovakia	C/KW											
Lithuania	R/KW											750
Romania	L/KW							708			8384	

RESIDENTIAL

Czechoslovakia	C/kwh	0.508	0.508	0.497	-	0.467	0.497	0.497				
Lithuania	R/kwh											0.35
Romania	L/kwh							0.85			0.85	

*** for industries < 1KV (Romania) or < 750KV (Lithuania)

demand charges are paid annually

HEAT		UNITS	1990				1991				1992		
			1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
INDUSTRIAL													
		Consumption Charge											
Czechoslovakia	C/GJ	57	57	56	56	56	58.2		102.98				
Lithuania	R/GJ												85.87
Romania	L/GJ							482			1100		
RESIDENTIAL													
Czechoslovakia	C/GJ	22	22	22	22	22	22						
Lithuania	R/GJ												11.48
Romania	L/GJ							88					

KEY

blank data not available
- assumed same price as previous period

EASTERN AND CENTRAL EUROPEAN ENERGY PRICING

EXCHANGE RATES**

NATION	Units	1990				1991				1992	
		1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q
Czechoslovakia	Crown/US\$	9.4	10	23.6	23.6	23.6	23.6	27.3	30.2	30.9	29.77
Lithuania*	Roubles/US\$	0.829	0.829	1.6	1.6	1.6	1.6	1.6	1.79	1.8	1.8
Romania	Lei/US\$	14.37	14.44	34.71	34.71	34.71	34.71	36.97	60.35	61.38	183

*1988-1991: official exchange rates for the USSR

**The exchange rates are accurate through 4th quarter 1990, after which multiple devaluations could occur per quarter. This is especially a problem in Lithuania and Romania late in 1991 and early in 1992.

ENERGY PRICES IN DOLLARS (\$US) INCLUDING TAX

AUTOMOTIVE FUELS

RETAIL		UNITS		1988		1989		1990		1991		1992	
				1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q	
<u>Leaded Premium</u>													
Czechoslovakia	\$/litre	0.85	0.80	0.53		0.57	0.76	0.66					
Lithuania	\$/litre												0.03
Romania	\$/litre												
<u>Unleaded Premium</u>													
Czechoslovakia	\$/litre		0.90	0.53		0.57	0.76	0.66					
Lithuania	\$/litre												
Romania	\$/litre												
<u>Leaded Regular</u>													
Czechoslovakia	\$/litre												
Lithuania	\$/litre												0.03
Romania	\$/litre							0.41			0.25		
<u>Unleaded Regular</u>													
Czechoslovakia	\$/litre												
Lithuania	\$/litre												
Romania	\$/litre												
<u>Diesel</u>													
Czechoslovakia	\$/litre	0.59	0.65	0.42		0.38	0.64	0.55					
Lithuania	\$/litre												0.03
Romania	\$/litre												
<u>LPG for Vehicles</u>													
Czechoslovakia	\$/GJ												
Lithuania	\$/GJ												0.02
Romania	\$/GJ												

AUTOMOTIVE FUELS

WHOLESALE	UNITS	1988	1989	1990	1990	1990	1990	1991	1991	1991	1991	1992
				1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
<u>Leaded Premium</u>												
Czechoslovakia	\$/tonne	377.66	247.40	104.92	104.92	104.92	104.92					
Lithuania	\$/tonne											21.98
Romania	\$/tonne											
<u>Unleaded Premium</u>												
Czechoslovakia	\$/tonne	377.66	247.40	104.92	104.92	104.92	104.92					
Lithuania	\$/tonne											
Romania	\$/tonne											
<u>Leaded Regular</u>												
Czechoslovakia	\$/tonne	377.66	247.40	104.92	104.92	104.92	104.92					
Lithuania	\$/tonne											15.48
Romania	\$/tonne											
<u>Unleaded Regular</u>												
Czechoslovakia	\$/tonne	377.66	247.40	104.92	104.92	104.92	104.92					
Lithuania	\$/tonne											
Romania	\$/tonne											
<u>Diesel</u>												
Czechoslovakia	\$/tonne	301.49	208.00	88.14	88.14	88.14	88.14					
Lithuania	\$/tonne											15.00
Romania	\$/tonne											
<u>LPG for Vehicles</u>												
Czechoslovakia	\$/GJ											
Lithuania	\$/tonne											14.88
Romania	\$/GJ											

FUEL OIL		1990				1991				1992		
RETAIL/RESIDENTIAL		1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
Light Fuel Oil	UNITS											
Czechoslovakia	\$/litre	87.23	82.00	34.75	34.75	34.75	34.75					
Lithuania	\$/tonne											15.84
Romania	\$/litre			54.02								
WHOLESALE/INDUSTRY												
Light Fuel Oil												
Czechoslovakia	\$/litre	2.61	2.48	1.57		1.33	2.51	2.00				
Lithuania	\$/tonne											14.88
Romania	\$/litre											
Heavy Fuel Oil												
Czechoslovakia	\$/tonne	243.62	17.00	115.17		116.95	199.58	156.48				
Lithuania	\$/tonne											9.76
Romania	\$/tonne		129.85					40.57				
LIQUID GAS		1990				1991				1992		
RETAIL		1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
Propane Butane Mix	UNITS											
Czechoslovakia	\$/GJ											
Lithuania	\$/GJ											0.26
Romania	\$/GJ											
LPG												
Czechoslovakia	\$/tonne	447.13	424.90									
Lithuania	\$/tonne											
Romania	\$/tonne											
Kerosine												
Czechoslovakia	\$/litre	0.53	0.50	0.25								
Lithuania	\$/tonne											
Romania	\$/litre											
WHOLESALE												
Propane Butane Mix												
Czechoslovakia	\$/tonne											
Lithuania	\$/tonne											14.79
Romania	\$/tonne											
LPG												
Czechoslovakia	\$/tonne	529.89	316.60									
Lithuania	\$/tonne											
Romania	\$/tonne											
Kerosine												
Czechoslovakia	\$/tonne	353.72	216.00	91.53								
Lithuania	\$/tonne											
Romania	\$/tonne											
CRUDE OIL		1990				1991				1992		
WHOLESALE		1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
Czechoslovakia	\$/tonne	239.36	155.00	65.68	65.68	65.68	223.73					
Lithuania	\$/tonne										7.00	
Romania	\$/tonne							216.39				139.21
NATURAL GAS		1990				1991				1992		
INDUSTRIAL USE		1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
Czechoslovakia	\$/10 ⁷ kcal	256.81	174.60			64.83	106.78	122.71				
Lithuania	\$/ m ³										23.33	
Romania	\$/tonne		69.25				60.67				32.79	
ELECTRIC GENERATION												
Czechoslovakia	\$/10 ⁷ kcal	256.81	174.60	99.79		85.89	141.44	162.60				
Lithuania	\$/ m ³										23.33	
Romania	\$/tonne		69.25				80.67				32.79	
RESIDENTIAL USE												
Czechoslovakia	\$/10 ⁷ kcal	114.89	105.80	44.83		44.83	44.83	38.75				
Lithuania	\$/ m ³											0.03
Romania	\$/tonne											

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COAL	UNITS			1990				1991				1992
		1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
INDUSTRIAL USE												
<u>Steam Coal</u>												
Czechoslovakia	\$/tonne	19.36	19.50	9.96		9.11	13.18	11.39	15.60			
Lithuania	\$/tonne											
Romania	\$/tonne		12.40					9.47			4.43	
<u>Coking Coal</u>												
Czechoslovakia	\$/tonne	75.00	91.70	4.00		38.86	55.93	53.74	55.00			
Lithuania	\$/tonne											
Romania	\$/tonne											
<u>Coal</u>												
Czechoslovakia	\$/tonne	102.69	131.49	57.20	57.20	57.20	57.20	70.85				
Lithuania	\$/tonne											
Romania	\$/tonne											
ELECTRIC GENERATION												
<u>Steam Coal</u>												
Czechoslovakia	\$/tonne	10.85	11.60	14.26		12.77	19.04	19.04				
Lithuania	\$/tonne											
Romania	\$/tonne							37.23			86.17	
RESIDENTIAL USE												
<u>Steam Coal</u>												
Czechoslovakia	\$/tonne	19.15	19.15	19.15		19.15	19.15	19.15				
Lithuania	\$/tonne											
Romania	\$/tonne											

ELECTRICITY	UNITS	1990				1991				1992			
		1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q	
LIGHT INDUSTRIAL***													
<u>Consumption Charge</u>													
Czechoslovakia	\$/kwh	0.05	0.05	0.06		0.05	0.06	0.06					
Lithuania	\$/kwh												
Romania	\$/kwh							0.23			1.35		
<u>Demand Charge#</u>													
Czechoslovakia	\$/KW												
Lithuania	\$/KW											79.79	
Romania	\$/KW										256.06		
HEAVY INDUSTRIAL													
<u>Consumption Charge</u>													
Czechoslovakia	\$/kwh												
Lithuania	\$/kwh											0.03	
Romania	\$/kwh		0.06					0.09			0.61		
<u>Demand Charge#</u>													
Czechoslovakia	\$/KW												
Lithuania	\$/KW											79.79	
Romania	\$/KW							75.32			679.15		
RESIDENTIAL													
Czechoslovakia	\$/kwh	0.05	0.05	0.05		0.05	0.05	0.05					
Lithuania	\$/kwh											0.04	
Romania	\$/kwh							0.07			0.07		

*** for industries < 1 KV (Romania) or < 750KV (Lithuania)

the demand charge is levied annually

				1990				1991				1992
HEAT	UNITS	1988	1989	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q
INDUSTRIAL												
Consumption Charge												
Czechoslovakia	\$/GJ	6.06	6.06	5.96	5.96	5.96	6.30		10.95			
Lithuania	\$/GJ											9.11
Romania	\$/GJ							49.15			117.02	
RESIDENTIAL												
Czechoslovakia	\$/GJ	2.34	2.34	2.34	2.34	2.34	2.34					
Lithuania	\$/GJ											1.22
Romania	\$/GJ							9.36				

Note. these tables are a prototype.

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LITHUANIAN ENERGY PRICES as of 1-Jan-1992
exchange rate (roubles/US\$)= 120

FUEL TYPES	PRICES	
	Roubles/Kwh	\$US/kwh
<u>Electricity</u>		
Residential:		
day rate	0.35	0.0029
night rate*	0.16	0.0013
Other:		
demand charge**	150	1.25
use charge	0.30	0.0025
Export to:		
Byelorussia	0.36	0.0030
Latvia	0.35	0.0029
Kaliningrad	0.35	0.0029

*Applied to metered residents between 11pm to 7am.

**In the units Roubles/KW*yr and \$US/KW*yr

Thermal Energy		
	Roubles/GJ	\$US/GJ
Residential:		
space & water	11.46	0.10
Enterprises and other consumers:		
state firm	85.76	0.71
state energy system		
demand charge*	1648.35	13.74
use charge	42.04	0.35
Greenhouses, garages and studios:		
state firm	85.76	0.71
state energy system	50.17	0.42

*In the units Roubles per month for 1 GJ/hour.

Oil Products

Retail:

	<u>Roubles/litre</u>	<u>Dollars/litre</u>
Gasoline*		
76 octane	3.5	0.03
92 octane	4	0.03
Diesel, 40-62 cetane	3	0.03

	<u>Roubles/tonne</u>	<u>Dollars/tonne</u>
Reactive fuel	1957	16.31
Boiler Fuel w/ ash	1268	10.56
Oil fuel, low ash	1270	10.58
Stove fuel for home	1877	15.64

*gasoline and deisel prices include a road and value added tax.

Wholesale:

	<u>Roubles/tonne</u>	<u>Dollars/tonne</u>
Gasoline		
76 octane noneth	1857	15.48
92 octane noneth	3080	25.67
92 octane ethylized	2195	18.29
Diesel		
40 cetane high Q	1825	15.21
62 cetane high Q	1825	15.21
40 cetane low Q	1775	14.79
62 cetane low Q	1775	14.79
Reactive fuel	1860	15.50
Boiler Fuel w/ ash	1170.5	9.75
Oil fuel, low ash	1172.5	9.77
Stove fuel for home	1785	14.88

<u>Liquid Gas</u>		Roubles per	Dollars per
Residential:		resident month	Resident month
with gas stoves and hot H2O.		8.93	0.074
with gas stoves but no hot H2O		14.92	0.12
for hot H2O		16.82	0.14
		Roubles/m ² of floor*month	Dollars/m ² of floor*month
for space heat		3.02	0.025
for greenhouses		26.27	0.22
Retail Prices:		Roubles/GJ	Dollars/GJ
propane and butane			
0.3kg cap. tank		31.34	0.26
2.05kg cap. tank		31.22	0.26
		Roubles/litre	Dollars/litre
LPG for vehicles		1.85	0.015
		Roubles/GJ	Dollars/GJ
LPG for vehicles		75.2	0.63
		Roubles/tonne	Dollars/tonne
liquid gas from distrib stations		2130	17.75
		Roubles/GJ	Dollars/GJ
liquid gas from distrib stations		46.81	0.39
Wholesale Prices:		Roubles/tonne	Dollars/tonne
Propane-butane mix		1775	14.79
Technical Butane		1775	14.79
LPG for Vehicles		1785	14.88
Butane		1795	14.96
Isobutane		2350	19.58
Propane-propilane		1783	14.85

Romanian Electricity Corporation

Electric Tariffs (Effective 11/15/91)

Tension Level	A. Differentiated Two Tiered Tariff**				B. Differentiated Single Level Tariff**		C. Simple Two Tiered Tariff**		D. Simple Single Level Tariff**
	for power*		for energy				Lei/kW annual	Lei/kWh	Lei/kWh
	Lei/kW		Lei/kW						
	year				Lei/ kWh				
	Peak hour	Remaining hours	Peak hour	Remaining hours	Peak hour	Remaining hours	for power	for energy	
1. Low tension (0, 1-1 kV year)	41268	17556	18.2	5.9	27.4	9.8	28884	9.5	12.7
2. Medium tension (1-110 kV year)	24780	10140	15.7	5.7	22.2	8.2	24060	7.9	10.5
3. High tension (110 kV day)	14820	6384	15.5	5.7	18.0	7.1	20052	6.9	8.9

* Used where equipment exists for measurement of maximum demand, otherwise estimates of peak power used.

**Tariff is determined by existence of functioning meters.

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END USE ENERGY PRICES

OECD - EUROPE

Sector	Fuel	US\$/toe	US\$/mmBtu	Comments
Transport	Gasoline	1106.6	27.89	Q2 1991 OECD Europe price
	Diesel	660.9	16.66	Q2 1991 OECD Europe price
Industrial	Light Fuel Oil	289.9	7.31	Q3 1991 Danish price, similar to OECD Europe Price
	Heavy Fuel Oil	150.8	3.80	Q2 1991 OECD Europe price
	Electricity	742.1	18.70	1989 OECD Europe price
	Natural Gas	151.2	3.81	1988 OECD Europe price
	Steam Coal	128.1	3.23	1989 OECD Europe price
	Coking Coal	91.7	2.31	1989 OECD Europe price
	Thermal	297.6	7.5	per discussion at RMA meeting
Household	Electricity	1281.7	32.30	1989 OECD Europe price
	Thermal	436.48	11	per discussion at RMA meeting

US PRICES

Sector	Fuel	US\$/toe	US\$/mmBtu	Comments
Transport	Gasoline	365.4	9.21	Q2 1991 price
	Diesel	335.8	8.46	Q2 1991 price
Industrial	Light Fuel Oil	186.6	4.70	Q2 1991 price
	Heavy Fuel Oil	78.8	1.99	Q2 1991 price
	Electricity	552.3	13.92	Q2 1991 price
	Natural Gas	101.9	2.57	Q2 1991 price
	Steam Coal	58.8	1.48	1990 price
	Coking Coal	61.6	1.55	Q2 1991 price
Household	Electricity	995.8	25.10	Q2 1991 price

Source: IEA, 1991, IEA Statistics, Energy Prices and Taxes;
Second Quarter 1991, OCDE/OCED Paris, pp.283-298.

Conversion Tables

CONVERSION TABLES

Length	
1 meter	= 39.3701 inches = 3.28084 feet
Area	
1 square meter	= 10.7639 square feet
1 square kilometer	= 0.386102 square mile = 100 hectares
1 hectare	= 10,000 square meters = 2.47105 acres
Volume	
1 liter	= 0.0353147 cubic foot = 0.264172 US gallon = 0.001 cubic meter = 0.219969 Imperial gallon
1 US barrel	= 5.6146 cubic foot = 0.158987 cubic meter = 42 US gallons = 34.9726 Imperial gallons
Mass	
1 kilogram	= 2.20462 pounds
1 short ton (US)	= 2,000 pounds = 0.907185 tonne = 0.892857 long ton
1 tonne (metric)	= 1,000 kilograms = 2,204.62 pounds = 0.984207 long ton = 1.10231 short tons
1 long ton (Imperial)	= 2,240 pounds = 1.12 short tons = 1.01605 tonnes

Energy and power

1 International table (IT) calorie	= 4.1868 joules
1 kilocalorie (IT)	= 1.163 watt hours
1 kilowatt hour	= 3412.14 BTUs = 895.845 kilocalories (IT) = 3.6 megajoules = 1.34102 horsepower-hours
1 metric horsepower	= 735.499 watts = 542.476 foot pounds force/second = 0.98632 Imperial horsepower
1 kilowatt	= 737.562 foot pounds force/second = 1.35962 metric horsepower

Approximate heat energy content of fuels

	BTU/lb	MJ/kg
Crude oil	18,300-19,500	42.6-45.4
Gasoline	20,500	47.7
Kerosene	19,800	46.1
Benzole	18,100	42.1
Ethanol	11,600	27.0
Gas oil	19,200	44.7
Fuel oil (bunker)	18,300	42.6
Coal (bituminous)	10,200-14,600	23.7-34.0
LNG (natural gas)	22,300	51.9

Product specific gravity ranges

	Specific Gravity	Barrels per tonne
Crude oil	0.80-0.97	8.0-6.6
Aviation gasoline	0.70-0.78	9.1-8.2
Motor gasoline	0.71-0.79	9.0-8.1
Kerosene	0.78-0.84	8.2-7.6
Gas oil	0.82-0.90	7.8-7.1
Diesel oil	0.82-0.92	7.8-6.9
Lubricating oil	0.85-0.95	7.5-6.7
Fuel oil	0.92-0.99	6.9-6.5
Asphaltic bitumen	1.00-1.10	6.4-5.8

ABBREVIATIONS

DIHP	- brake horsepower
BTU	- British thermal unit
CIF	- cost including insurance and freight
CPI	- consumer price index
DWT	- deadweight tons or tonnage
GNP	- gross national product
GWH	- gigawatt-hour
KV	- kilovolt
KW	- kilowatt
KWH	- kilowatt-hour
MB	- thousand barrels
MBCD	- thousand barrels per calendar day
MBSD	- thousand barrels per stream day
MJ	- megajoules
MMB	- million barrels
MMBOE	- million barrels-of-oil equivalent
MT	- metric tons
MVA	- megavolt ampere
MW	- megawatt
bbbl	- barrel

Converting into Barrels-of-Oil Equivalent (BOE)

Energy forms are converted into a common unit, BOE, based on fuel oil equivalent at 18,600 Btu/lb as follows:

Electricity	600 kwh	1.0000
Regular Gasoline	1 bbl	0.8470
Premium	1 bbl	0.8624
Kerosene	1 bbl	0.8798
Diesel Oil	1 bbl	0.9328
LPG	1 bbl	0.6384
Aviation Gas	1 bbl	0.8475
Aviation Turbo	1 bbl	0.798
Fuel Oil		
Pitch	1 bbl	1.0058
P/C	1 bbl	1.0197
Coal (10,000 BTU/lb)	1 MT	3.530
Alcohol	1 bbl	0.5561
Bagasse	1 MT	1.440
Coconut Oil	1 bbl	1.000

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TABLE B-60.—Consumer price indexes, commodities, services, and special groups, 1946-90
[1982-84 = 100]

Year or month	All items	Commodities					Services			Special indexes			
		All commodities	Food	Commodities less food			All services	Medical care services	Services less medical care	All items less food	All items less energy	All items less food and energy	Energy ¹
				All	Durable	Non-durable							
1946.....	19.5	22.9	19.8	26.3	29.2	23.5	14.1	10.4		19.8			
1947.....	22.3	27.6	24.1	29.7	31.7	27.1	14.7	11.3		21.7			
1948.....	24.1	29.6	26.1	31.9	34.0	29.2	15.6	12.1		23.3			
1949.....	23.8	28.8	25.0	31.5	34.5	28.7	16.4	12.5		23.5			
1950.....	24.1	29.0	25.4	31.4	34.9	28.6	16.9	12.8		23.8			
1951.....	26.0	31.6	28.2	33.8	37.5	30.8	17.8	13.4		25.3			
1952.....	26.5	32.0	28.7	34.1	38.0	31.0	18.6	14.3		25.9			
1953.....	26.7	31.9	28.3	34.2	37.7	31.2	19.4	14.8		26.4			
1954.....	26.9	31.6	28.2	33.8	36.8	31.4	20.0	15.3		26.6			
1955.....	26.8	31.3	27.8	33.6	36.1	31.4	20.4	15.7		26.6			
1956.....	27.2	31.6	28.0	33.9	36.1	32.0	20.9	16.3		27.1			
1957.....	28.1	32.6	28.9	34.9	37.2	32.9	21.8	17.0	22.8	28.0	28.9	28.9	21.5
1958.....	28.9	33.3	30.2	35.3	37.8	33.1	22.6	17.9	23.6	28.6	29.7	29.6	21.5
1959.....	29.1	33.3	29.7	35.8	38.4	33.5	23.3	18.7	24.2	29.2	29.9	30.2	21.9
1960.....	29.6	33.6	30.0	36.0	38.1	34.1	24.1	19.5	25.0	29.7	30.4	30.6	22.4
1961.....	29.9	33.8	30.4	36.1	38.1	34.3	24.5	20.2	25.4	30.0	30.7	31.0	22.5
1962.....	30.2	34.1	30.6	36.3	38.5	34.5	25.0	20.9	25.9	30.3	31.1	31.4	22.6
1963.....	30.6	34.4	31.1	36.6	38.6	34.8	25.5	21.5	26.3	30.7	31.5	31.8	22.6
1964.....	31.0	34.8	31.5	36.9	39.0	35.1	26.0	22.0	26.8	31.1	32.0	32.3	22.5
1965.....	31.5	35.2	32.2	37.2	38.8	35.6	26.6	22.7	27.4	31.6	32.5	32.7	22.9
1966.....	32.4	36.1	33.8	37.7	38.9	36.4	27.6	23.9	28.3	32.3	33.5	33.5	23.3
1967.....	33.4	36.8	34.1	38.6	39.4	37.6	28.8	26.0	29.3	33.4	34.4	34.7	23.8
1968.....	34.8	38.1	35.3	40.0	40.7	39.1	30.3	27.9	30.8	34.9	35.9	36.3	24.2
1969.....	36.7	39.9	37.1	41.7	42.2	40.9	32.4	30.2	32.9	36.8	38.0	38.4	24.8
1970.....	38.8	41.7	39.2	43.4	44.1	42.5	35.0	32.3	35.6	39.0	40.3	40.8	25.5
1971.....	40.5	43.2	40.4	45.1	46.0	44.0	37.0	34.7	37.5	40.8	42.0	42.7	26.5
1972.....	41.8	44.5	42.1	46.1	46.9	45.0	38.4	35.9	38.9	42.0	43.4	44.0	27.2
1973.....	44.4	47.8	48.2	47.7	48.1	46.9	40.1	37.5	40.6	43.7	46.1	45.6	29.4
1974.....	49.3	53.5	55.1	52.8	51.5	52.9	43.8	41.4	44.3	48.0	50.6	49.4	38.1
1975.....	53.8	58.2	59.8	57.6	57.4	57.0	48.0	46.6	48.3	52.5	55.1	53.9	42.1
1976.....	56.9	60.7	61.6	60.5	60.9	59.5	52.0	51.3	52.2	56.0	58.2	57.4	45.1
1977.....	60.6	64.2	65.5	63.8	64.4	62.5	56.0	56.4	55.9	59.6	61.9	61.0	49.4
1978.....	65.2	68.8	72.0	67.6	68.6	65.5	60.8	61.2	60.7	63.9	66.7	65.5	52.5
1979.....	72.6	76.6	79.9	75.3	75.4	74.6	67.5	67.2	67.5	71.2	73.4	71.9	65.7
1980.....	82.4	86.0	86.8	85.7	83.0	88.4	77.9	74.8	78.2	81.5	81.9	80.8	86.0
1981.....	90.9	93.2	93.6	93.1	89.6	96.7	88.1	82.8	88.7	90.4	90.1	89.2	97.7
1982.....	96.5	97.0	97.4	96.9	95.1	98.3	96.0	92.6	96.4	96.3	96.1	95.8	99.2
1983.....	99.6	99.8	99.4	100.0	99.8	100.0	99.4	100.7	99.2	99.7	99.6	99.8	99.9
1984.....	103.9	103.2	103.2	103.1	105.1	101.7	104.6	106.7	104.4	104.0	104.3	104.6	100.9
1985.....	107.6	105.4	105.6	105.2	106.8	104.1	109.9	113.2	109.6	108.0	108.4	109.1	101.6
1986.....	109.6	104.4	109.0	101.7	106.6	98.5	115.4	121.9	114.6	109.8	112.6	113.5	88.2
1987.....	113.6	107.7	113.5	104.3	108.2	101.8	120.2	130.0	119.1	113.6	117.2	118.2	88.6
1988.....	118.3	111.5	118.2	107.7	110.4	105.8	125.7	138.3	124.3	118.3	122.3	123.4	89.3
1989.....	124.0	116.7	125.1	112.0	112.2	111.7	131.9	148.9	130.1	123.7	128.1	129.0	94.3
1990.....	130.7	122.8	132.4	117.4	113.4	119.9	139.2	162.7	136.8	130.3	134.7	135.5	102.1
1989: Jan.....	121.1	113.9	122.2	109.2	112.5	107.1	128.9	143.5	127.3	120.8	125.5	126.4	89.0
1989: Feb.....	121.6	114.3	122.9	109.5	112.4	107.6	129.4	145.1	127.8	121.3	126.0	126.9	89.3
1989: Mar.....	122.3	115.2	123.5	110.5	111.9	109.4	130.0	145.9	128.3	122.0	126.7	127.6	89.8
1989: Apr.....	123.1	116.7	124.2	112.5	111.8	112.8	130.2	146.4	128.5	122.9	127.1	128.0	94.9
1989: May.....	123.8	117.5	124.9	113.2	111.9	113.9	130.8	146.9	129.1	123.5	127.6	128.3	97.4
1989: June.....	124.1	117.2	125.0	112.8	112.1	113.1	131.6	147.9	129.9	123.9	127.7	128.5	99.0
1989: July.....	124.4	117.0	125.5	112.1	111.9	112.2	132.5	149.3	130.8	124.2	128.2	129.0	98.5
1989: Aug.....	124.6	116.7	125.8	111.6	111.4	111.5	133.1	150.4	131.3	124.3	128.5	129.3	97.0
1989: Sept.....	125.0	117.3	126.1	112.4	111.3	112.9	133.4	151.3	131.6	124.8	129.1	130.0	95.9
1989: Oct.....	125.6	118.1	126.5	113.4	112.1	114.1	133.7	152.3	131.8	125.4	129.9	130.9	94.6
1989: Nov.....	125.9	118.3	126.9	113.4	113.0	113.6	134.1	153.6	132.1	125.6	130.4	131.3	93.2
1989: Dec.....	126.1	118.2	127.4	113.0	113.5	112.6	134.6	154.1	132.6	125.8	130.6	131.5	93.2
1990: Jan.....	127.4	119.9	130.4	114.1	113.8	114.2	135.4	155.7	133.4	126.7	131.5	132.0	97.6
1990: Feb.....	128.0	120.6	131.3	114.6	113.7	115.0	136.0	157.2	133.9	127.3	132.3	132.8	96.4
1990: Mar.....	128.7	121.1	131.5	115.4	113.4	116.5	136.9	158.5	134.7	128.1	133.3	133.9	95.5
1990: Apr.....	128.9	121.4	131.3	115.9	113.1	117.4	137.1	159.4	134.9	128.4	133.5	134.2	95.7
1990: May.....	129.2	121.4	131.3	115.9	113.2	117.5	137.6	160.5	135.3	128.7	133.7	134.4	96.7
1990: June.....	129.9	121.6	132.0	115.8	112.9	117.6	138.8	161.5	136.5	129.4	134.2	134.8	99.5
1990: July.....	130.4	121.6	132.7	115.5	113.0	117.0	139.9	163.4	137.5	130.0	134.8	135.5	98.9
1990: Aug.....	131.6	122.8	132.9	117.2	112.9	119.9	140.9	165.0	138.5	131.3	135.6	136.4	103.6
1990: Sept.....	132.7	124.6	133.2	119.8	112.8	124.1	141.4	165.8	139.0	132.6	136.3	137.2	108.8
1990: Oct.....	133.5	126.1	133.6	121.8	113.6	126.8	141.7	167.2	139.1	133.5	136.9	137.8	111.4
1990: Nov.....	133.8	126.3	134.0	121.8	114.1	126.6	142.0	168.6	139.4	133.7	137.2	138.2	110.9
1990: Dec.....	133.8	126.0	134.2	121.4	114.5	125.7	142.3	169.3	139.7	133.7	137.4	138.3	110.1

¹ Household fuels—gas (piped), electricity, fuel oil, etc.—and motor fuel. Motor oil, coolant, etc. also included through 1982.
Note.—Data beginning 1978 are for all urban consumers; earlier data are for urban wage earners and clerical workers.
See also Note, Table B-58.

Source: Department of Labor, Bureau of Labor Statistics.

TABLE B-59.—Consumer price indexes, selected expenditure classes, 1946-90—Continued
[1982-84=100, except as noted]

Year or month	Transportation							Medical care		
	Total	Private transportation					Public transportation	Total	Medical care commodities	Medical care services
		Total ^a	New cars	Used cars	Motor fuel ^a	Auto-mobile maintenance and repairs				
1946	16.7	18.3			14.5	15.8				
1947	18.5	20.8	34.1		16.4	17.1	9.4	12.5	34.2	10.4
1948	20.6	23.0	37.3		18.6	18.1	9.9	13.5	36.7	11.3
1949	22.1	24.4	40.8		19.1	18.6	11.2	14.4	38.6	12.1
1950	22.7	24.5	41.1		19.0	18.9	12.4	14.8	39.2	12.5
1951	24.1	25.6	43.1		19.5	20.4	13.4	15.1	39.7	12.8
1952	25.7	27.3	46.8		20.0	20.8	14.8	15.9	40.8	13.4
1953	26.5	27.8	47.2	26.7	21.2	22.0	15.8	16.7	41.2	14.3
1954	26.1	27.1	46.5	22.7	21.8	22.7	16.8	17.3	41.5	14.8
1955	25.8	26.7	44.8	21.5	22.1	23.2	18.0	17.8	42.0	15.3
1956	26.2	27.1	46.1	20.7	22.8	24.2	18.5	18.2	42.5	15.7
1957	27.7	28.6	48.5	23.2	23.8	25.0	19.2	18.9	43.4	16.3
1958	28.6	29.5	50.0	24.0	23.4	25.4	19.9	19.7	44.6	17.0
1959	29.8	30.8	52.2	26.8	23.7	26.0	20.9	20.6	46.1	17.9
1960	29.8	30.6	51.5	25.0	24.4	26.5	21.5	21.5	46.8	18.7
1961	30.1	30.8	51.5	26.0	24.1	27.1	22.2	22.3	46.9	19.5
1962	30.8	31.4	51.3	28.4	24.3	27.5	23.2	22.9	46.5	20.2
1963	30.9	31.6	51.0	28.7	24.2	27.8	24.0	23.5	45.6	20.9
1964	31.4	32.0	50.9	30.0	24.1	28.2	24.3	24.1	45.2	21.5
1965	31.9	32.5	49.7	29.8	25.1	28.7	24.7	24.6	45.1	22.0
1966	32.3	32.9	48.8	29.0	25.6	29.2	25.2	25.2	45.0	22.7
1967	33.3	33.8	49.3	29.9	26.4	30.4	26.1	26.3	45.1	23.9
1968	34.3	34.8	50.7	(*)	26.8	32.1	27.4	28.2	44.9	26.0
1969	35.7	36.0	51.5	30.9	27.6	34.1	28.7	29.9	45.0	27.9
1970	37.5	37.5	53.0	31.2	27.9	36.6	30.9	31.9	45.4	30.2
1971	39.5	39.4	55.2	33.0	28.1	39.3	35.2	34.0	46.5	32.3
1972	39.9	39.7	54.7	33.1	28.4	41.1	37.8	36.1	47.3	34.7
1973	41.2	41.0	54.8	35.2	31.2	43.2	39.3	37.3	47.4	35.9
1974	45.8	46.2	57.9	36.7	42.2	47.6	39.7	38.8	47.5	37.5
1975	50.1	50.6	62.9	43.8	45.1	53.7	40.6	42.4	49.2	41.4
1976	55.1	55.6	66.9	50.3	47.0	57.6	43.5	47.5	53.3	46.6
1977	59.0	59.7	70.4	54.7	49.7	61.9	47.8	52.0	56.5	51.3
1978	61.7	62.5	75.8	55.8	51.8	67.0	50.0	57.0	60.2	56.4
1979	70.5	71.7	81.8	60.2	70.1	73.7	51.5	61.8	64.4	61.2
1980	83.1	84.2	88.4	62.3	97.4	81.5	54.9	67.5	69.0	67.2
1981	93.2	93.8	93.7	76.9	108.5	89.2	69.0	74.9	75.4	74.8
1982	97.0	97.1	97.4	88.8	102.8	96.0	85.6	82.9	83.7	82.8
1983	99.3	99.3	99.9	98.7	99.4	100.3	97.7	94.9	92.5	92.6
1984	103.7	103.6	102.8	112.5	97.9	103.8	99.5	100.6	100.2	100.7
1985	106.4	106.2	106.1	113.7	98.7	106.8	105.7	106.8	107.5	106.7
1986	102.3	101.2	110.6	108.8	77.1	110.3	110.5	113.5	115.2	113.2
1987	105.4	104.2	114.6	113.1	80.2	114.8	117.0	122.0	122.8	121.9
1988	108.7	107.6	116.9	118.0	80.9	119.7	121.1	130.1	131.0	130.0
1989	114.1	112.9	119.2	120.4	88.5	124.9	123.3	138.6	139.9	138.3
1990	120.5	118.8	121.0	117.6	101.2	130.1	129.5	149.3	150.8	148.9
1989 Jan	111.1	109.8	119.5	120.5	79.6	122.4	142.6	162.8	163.4	162.7
1989 Feb	111.6	110.3	119.6	120.5	80.3	123.3	127.5	143.8	145.0	143.5
1989 Mar	111.9	110.7	119.6	120.5	81.5	123.5	128.1	145.2	145.8	145.1
1989 Apr	114.6	113.6	119.4	120.7	92.1	123.8	128.2	146.1	147.2	145.9
1989 May	116.0	115.0	119.5	121.0	96.6	124.3	128.4	146.8	148.4	146.4
1989 June	115.9	114.9	119.1	121.3	96.0	124.5	128.9	147.5	150.0	146.9
1989 July	115.4	114.3	118.6	121.1	94.4	124.8	129.6	148.5	151.0	147.9
1989 Aug	114.3	113.1	117.7	120.3	91.0	125.4	129.7	149.7	151.4	149.3
1989 Sept	113.7	112.4	117.0	119.8	88.8	126.2	130.1	150.7	152.1	150.4
1989 Oct	114.5	113.3	118.6	119.7	88.9	126.7	130.1	151.7	153.3	151.3
1989 Nov	115.0	113.7	120.5	120.1	87.2	126.7	130.6	152.7	154.1	152.3
1989 Dec	115.2	113.9	121.8	119.7	85.8	126.9	131.3	153.9	155.3	153.6
1990 Jan	117.2	115.9	122.3	118.9	91.4	127.3	131.7	154.4	156.0	154.1
1990 Feb	117.1	115.6	121.9	117.4	90.6	127.6	134.2	155.9	156.9	155.7
1990 Mar	116.8	115.1	121.3	116.6	89.3	128.8	136.7	157.5	158.6	157.2
1990 Apr	117.3	115.5	120.7	116.2	91.2	129.4	139.1	158.7	159.9	158.5
1990 May	117.7	115.9	120.7	116.9	92.5	129.4	140.3	159.8	161.3	159.4
1990 June	118.2	116.4	120.3	117.6	94.6	129.6	140.9	160.8	162.2	160.5
1990 July	118.4	116.6	119.8	118.2	94.3	130.2	141.5	161.9	163.3	161.5
1990 Aug	120.6	119.0	119.5	118.3	103.2	130.4	141.6	163.5	164.1	163.4
1990 Sept	123.0	121.4	119.0	118.3	112.0	131.5	141.9	165.0	164.8	165.0
1990 Oct	125.8	124.2	120.5	118.1	118.9	132.1	144.0	165.8	166.0	165.8
1990 Nov	126.9	125.1	122.1	117.2	119.0	132.5	146.0	167.1	166.8	167.2
1990 Dec	127.2	125.1	123.5	117.1	117.1	132.5	150.3	168.4	167.8	168.6
							154.4	169.2	169.1	169.3

^a Includes direct pricing of new trucks and motorcycles beginning September 1982.

^a Includes direct pricing of diesel fuel and gasoline beginning September 1981.

^a Not available.

Note.—Data beginning 1978 are for all urban consumers; earlier data are for urban wage earners and clerical workers. See also Note, Table B-58.

Source: Department of Labor, Bureau of Labor Statistics.

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TABLE B-59.—Consumer price indexes, selected expenditure classes, 1946-90
[1982-84 = 100, except as noted]

Year or month	Food and beverages			Shelter					Fuel and other utilities					
	Total ¹	Food		Total	Renters' costs		Home-owners' costs ²	Home maintenance and repairs	Total	Household fuels			Other utilities and public services	
		Total	At home		Away from home	Total ³				Rent, residential	Total	Fuel oil and other household fuel commodities		Gas (piped) and electricity
1946		19.8				25.0					7.9	18.3		
1947		24.1	25.8			25.8					9.0	18.2		
1948		26.1	28.0			27.5					10.6	18.7		
1949		25.0	26.9			28.7					10.9	19.2		
1950		25.4	27.3			29.7					11.3	19.2		
1951		28.2	30.3			30.9					11.8	19.3		
1952		28.7	30.8			32.2					12.1	19.5		
1953		28.3	30.3	21.5	22.0	33.9		20.5	22.5		12.6	19.9		
1954		28.2	30.1	21.9	22.5	35.1		20.9	22.6		12.6	20.2		
1955		27.8	29.5	22.1	22.7	35.6		21.4	23.0		12.7	20.7		
1956		28.0	29.6	22.6	23.1	36.3		22.3	23.6		13.3	20.9		
1957		28.9	30.6	23.4	24.0	37.0		23.2	24.3		14.0	21.1		
1958		30.2	32.0	24.1	24.5	37.6		23.6	24.8		13.7	21.9		
1959		29.7	31.2	24.8	24.7	38.2		24.0	25.4		13.9	22.4		
1960		30.0	31.5	25.4	25.2	38.7		24.4	26.0		13.8	23.3		
1961		30.4	31.8	26.0	25.4	39.2		24.8	26.3		14.1	23.5		
1962		30.6	32.0	26.7	25.8	39.7		25.0	26.3		14.2	23.5		
1963		31.1	32.4	27.3	26.1	40.1		25.3	26.6		14.4	23.5		
1964		31.5	32.7	27.8	26.5	40.5		25.8	26.6		14.4	23.5		
1965		32.2	33.5	28.4	27.0	40.9		26.3	26.6		14.6	23.5		
1966		33.8	35.2	29.7	27.8	41.5		27.5	26.7		15.0	23.6		
1967	35.0	34.1	35.1	31.3	28.8	42.2		28.9	27.1	21.4	15.5	23.7	46.6	
1968	36.2	35.3	36.3	32.9	30.1	43.3		30.6	27.4	21.7	16.0	23.9	47.1	
1969	38.1	37.1	38.0	34.9	32.6	44.7		33.2	28.0	22.1	16.3	24.3	48.4	
1970	40.1	39.2	39.9	37.5	35.5	46.5		35.8	29.1	23.1	17.0	25.4	50.0	
1971	41.4	40.4	40.9	39.4	37.0	48.7		38.6	31.1	24.7	18.2	27.1	53.4	
1972	43.1	42.1	42.7	41.0	38.7	50.4		40.6	32.5	25.7	18.3	28.5	56.2	
1973	48.8	48.2	49.7	44.2	40.5	52.5		43.6	34.3	27.5	21.1	29.9	57.8	
1974	55.5	55.1	57.1	49.8	44.4	55.2		49.5	40.7	34.4	33.2	34.5	60.7	
1975	60.2	59.8	61.8	54.5	48.8	58.0		54.1	45.4	39.4	36.4	40.1	63.9	
1976	62.1	61.6	63.1	58.2	51.5	61.1		57.6	49.4	43.3	38.8	44.7	67.7	
1977	65.8	65.5	66.8	62.6	54.9	64.8		62.0	54.7	49.0	43.9	50.5	70.8	
1978	72.2	72.0	73.8	68.3	60.5	69.3		67.2	58.5	53.0	46.2	55.0	73.7	
1979	79.9	79.9	81.8	75.9	68.9	74.3		74.0	64.8	61.3	62.4	61.0	74.3	
1980	86.7	86.8	88.4	83.4	81.0	80.9		82.4	75.4	74.8	86.1	71.4	77.0	
1981	93.5	93.6	94.8	90.5	90.5	87.9		90.7	86.4	87.2	104.6	81.9	84.3	
1982	97.3	97.4	98.1	95.8	96.9	94.6		96.4	94.9	95.6	103.4	93.2	93.3	
1983	99.5	99.4	99.1	100.0	99.1	103.0	100.1	102.5	99.9	100.2	100.5	97.2	101.5	99.5
1984	103.2	103.2	102.8	104.2	104.0	108.6	105.3	107.3	103.7	104.8	104.0	99.4	105.4	107.2
1985	105.6	105.6	104.3	108.3	109.8	115.4	111.8	113.1	106.5	106.5	104.5	95.9	107.1	112.1
1986	109.1	109.0	107.3	112.5	115.8	121.9	118.3	119.4	107.9	104.1	99.2	77.6	105.7	117.9
1987	113.5	113.5	111.9	117.0	121.3	128.1	123.1	124.8	111.8	103.0	97.3	77.9	103.8	120.1
1988	118.2	118.2	116.6	121.8	127.1	133.6	127.8	131.1	114.7	104.4	98.0	78.1	104.6	122.9
1989	124.9	125.1	124.2	127.4	132.8	138.9	132.8	137.3	118.0	107.8	100.9	81.7	107.5	127.1
1990	132.1	132.4	132.3	133.4	140.0	146.7	138.4	144.6	122.2	111.6	104.5	99.3	109.3	131.7
1989 Jan	122.0	122.2	121.2	124.7	129.8	135.2	130.5	134.4	116.1	106.0	98.7	80.5	105.1	125.9
Feb	122.7	122.9	122.0	125.2	130.3	136.3	130.9	134.7	117.1	105.9	98.6	81.4	104.9	126.0
Mar	123.3	123.5	122.7	125.7	131.2	138.6	131.1	135.0	117.1	105.9	98.5	81.5	104.8	125.9
Apr	124.0	124.2	123.5	126.2	131.2	137.9	131.4	135.4	117.3	106.2	98.8	82.5	105.0	126.2
May	124.7	124.9	124.4	126.7	131.8	137.8	131.7	136.2	117.4	107.0	99.6	81.5	106.1	127.0
June	124.9	125.0	124.3	127.1	132.3	138.7	132.3	136.5	118.3	109.2	103.2	80.2	110.5	127.1
July	125.4	125.5	124.8	127.8	133.6	141.5	133.0	137.3	118.4	109.7	103.7	79.7	111.1	127.7
Aug	125.6	125.8	124.9	128.1	134.1	141.5	133.5	138.1	118.5	109.7	103.7	78.9	111.3	127.8
Sept	125.9	126.1	125.0	128.8	134.1	139.4	133.9	138.9	118.6	109.7	103.5	79.3	111.0	128.1
Oct	126.3	126.5	125.4	129.1	134.8	140.0	134.7	139.7	118.6	108.0	101.0	82.0	107.6	127.6
Nov	126.7	126.9	125.8	129.5	135.2	140.1	135.2	140.3	119.3	107.5	99.9	83.9	106.1	127.9
Dec	127.2	127.4	126.5	129.8	135.6	140.1	135.5	140.9	119.5	108.4	101.2	88.7	107.0	128.2
1990 Jan	130.0	130.4	131.0	130.3	136.3	142.0	135.8	141.1	120.4	110.8	104.5	113.1	107.5	129.3
Feb	130.9	131.3	132.1	131.0	136.6	143.5	136.0	141.0	120.8	110.2	103.1	95.4	108.3	130.0
Mar	131.2	131.5	131.9	131.8	137.8	144.8	136.5	142.2	121.2	109.9	102.3	91.5	107.9	130.7
Apr	131.0	131.3	131.1	132.5	138.0	144.7	137.0	142.5	121.2	109.4	101.2	89.6	106.8	130.9
May	131.1	131.3	130.9	133.0	138.3	144.4	137.3	143.1	122.2	109.9	101.9	88.0	107.8	131.2
June	131.7	132.0	131.7	133.4	139.5	145.3	137.9	144.4	121.8	112.2	105.4	84.9	112.4	131.8
July	132.4	132.7	132.5	133.9	141.1	148.7	138.7	145.4	122.1	111.3	104.5	82.7	111.7	130.8
Aug	132.7	132.9	132.7	134.3	142.4	150.7	139.4	146.5	121.2	112.7	105.6	91.8	111.6	132.8
Sept	133.0	133.2	132.9	134.6	142.3	148.9	140.0	147.0	124.6	114.0	107.6	104.4	112.4	132.9
Oct	133.4	133.6	133.4	135.0	142.4	148.9	140.5	147.2	123.4	113.4	106.4	118.5	109.0	133.4
Nov	133.7	134.0	133.8	135.4	142.4	149.0	140.7	147.3	123.9	112.9	105.4	117.0	108.0	133.7
Dec	133.9	134.2	133.8	135.7	142.7	149.5	141.1	147.5	123.8	112.7	105.6	114.1	108.6	132.7

¹ Includes alcoholic beverages, not shown separately.
² December 1982 = 100

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PRICES

TABLE B-59.—Consumer price indexes, major expenditure classes, 1946-90

(1982-84=100)

Year or month	All items	Food and beverages		Housing				Apparel and upkeep	Transportation	Medical care	Entertainment	Other goods and services	Energy ³
		Total ¹	Food	Total	Shelter	Fuel and other utilities ²	Household furnishings and operation						
1946.....	19.5		19.8					34.4	16.7	12.5			
1947.....	22.3		24.1					39.9	18.5	13.5			
1948.....	24.1		26.1					42.5	20.6	14.4			
1949.....	23.8		25.0					40.8	22.1	14.8			
1950.....	24.1		25.4					40.3	22.7	15.1			
1951.....	26.0		28.2					43.9	24.1	15.9			
1952.....	26.5		28.7					43.5	25.7	16.7			
1953.....	26.7		28.3		22.0	22.5		43.1	26.5	17.3			
1954.....	26.9		28.2		22.5	22.6		43.1	26.1	17.8			
1955.....	26.8		27.8		22.7	23.0		42.9	25.8	18.2			
1956.....	27.2		28.0		23.1	23.6		43.7	26.2	18.9			
1957.....	28.1		28.9		24.0	24.3		44.5	27.7	19.7			21.5
1958.....	28.9		30.2		24.5	24.8		44.6	28.6	20.6			21.5
1959.....	29.1		29.7		24.7	25.4		45.0	29.8	21.5			21.9
1960.....	29.6		30.0		25.2	26.0		45.7	29.8	22.3			22.4
1961.....	29.9		30.4		25.4	26.3		46.1	30.1	22.9			22.5
1962.....	30.2		30.6		25.8	26.3		46.3	30.8	23.5			22.6
1963.....	30.6		31.1		26.1	26.6		46.9	30.9	24.1			22.6
1964.....	31.0		31.5		26.5	26.6		47.3	31.4	24.6			22.5
1965.....	31.5		32.2		27.0	26.6		47.8	31.9	25.2			22.9
1966.....	32.4		33.8		27.8	26.7		49.0	32.3	26.3			23.3
1967.....	33.4	35.0	34.1	30.8	28.8	27.1	42.0	51.0	33.3	28.2	40.7	35.1	23.8
1968.....	34.8	36.2	35.3	32.0	30.1	27.4	43.6	53.7	34.3	29.9	43.0	36.9	24.2
1969.....	36.7	38.1	37.1	34.0	32.6	28.0	45.2	56.8	35.7	31.9	45.2	38.7	24.8
1970.....	38.8	40.1	39.2	36.4	35.5	29.1	46.8	59.2	37.5	34.0	47.5	40.9	25.5
1971.....	40.5	41.4	40.4	38.0	37.0	31.1	48.6	61.1	39.5	36.1	50.0	42.9	26.5
1972.....	41.8	43.1	42.1	39.4	38.7	32.5	49.7	62.3	39.9	37.3	51.5	44.7	27.2
1973.....	44.4	48.8	48.2	41.2	40.5	34.3	51.1	64.6	41.2	38.8	52.9	46.4	29.4
1974.....	49.3	55.5	55.1	45.8	44.4	40.7	56.8	69.4	45.8	42.4	56.9	49.8	38.1
1975.....	53.8	60.2	59.8	50.7	48.8	45.4	63.4	72.5	50.1	47.5	62.0	53.9	42.1
1976.....	56.9	62.1	61.6	53.8	51.5	49.4	67.3	75.2	55.1	52.0	65.1	57.0	45.1
1977.....	60.6	65.8	65.5	57.4	54.9	54.7	70.4	78.6	59.0	57.0	68.3	60.4	49.4
1978.....	65.2	72.2	72.0	62.4	60.5	58.5	74.7	81.4	61.7	61.8	71.9	64.3	52.5
1979.....	72.6	79.9	79.9	70.1	68.9	64.8	79.9	84.9	70.5	67.5	76.7	68.9	65.7
1980.....	82.4	86.7	86.8	81.1	81.0	75.4	86.3	90.9	83.1	74.9	83.6	75.2	86.0
1981.....	90.9	93.5	93.6	90.4	90.5	86.4	93.0	95.3	93.2	82.9	90.1	82.6	97.7
1982.....	96.5	97.3	97.4	96.9	96.9	94.9	98.0	97.8	97.0	92.5	96.0	91.1	99.2
1983.....	99.6	99.5	99.4	99.5	99.1	100.2	100.2	100.2	99.3	100.6	100.1	101.1	99.9
1984.....	103.9	103.2	103.2	103.6	104.0	104.8	101.9	102.1	103.7	106.8	103.8	107.9	100.9
1985.....	107.6	105.6	105.6	107.7	109.8	106.5	103.8	105.0	106.4	113.5	107.9	114.5	101.6
1986.....	109.6	109.1	109.0	110.9	115.8	104.1	105.2	105.9	102.3	122.0	111.6	121.4	88.2
1987.....	113.6	113.5	113.5	114.2	121.3	103.0	107.1	110.6	105.4	130.1	115.3	128.5	88.6
1988.....	118.3	118.2	118.2	118.5	127.1	104.4	109.4	115.4	108.7	138.6	120.3	137.0	89.3
1989.....	124.0	124.9	125.1	123.0	132.8	107.8	111.2	118.6	114.1	149.3	126.5	147.7	94.3
1990.....	130.7	132.1	132.4	128.5	140.0	111.6	113.3	124.1	120.5	162.8	132.4	159.0	102.1
1989: Jan.....	121.1	122.0	122.2	120.7	129.8	106.0	110.9	115.3	111.1	143.8	125.8	143.4	89.0
Feb.....	121.6	122.7	122.9	121.1	130.3	105.9	110.9	115.3	111.6	145.2	124.3	144.1	89.3
Mar.....	122.3	123.3	123.5	121.5	131.2	105.9	110.5	119.3	111.9	146.1	124.7	144.4	89.8
Apr.....	123.1	124.0	124.2	121.6	131.2	106.2	110.7	120.9	114.6	146.8	125.4	144.7	94.9
May.....	123.8	124.7	124.9	122.1	131.8	107.0	110.8	120.4	116.0	147.5	125.5	145.4	97.4
June.....	124.1	124.9	125.0	122.9	132.3	109.2	111.1	117.8	115.9	148.5	126.2	146.3	99.0
July.....	124.4	125.4	125.5	123.9	133.6	109.7	111.4	115.0	115.4	149.7	126.9	147.3	98.5
Aug.....	124.6	125.6	125.8	124.2	134.1	109.7	111.4	115.0	114.3	150.7	127.3	148.7	97.0
Sept.....	125.0	125.9	126.1	124.3	134.1	109.7	111.7	120.0	113.7	151.7	127.8	151.2	95.9
Oct.....	125.6	126.3	126.5	124.4	134.8	108.0	111.9	122.7	114.5	152.7	128.4	151.8	94.6
Nov.....	125.9	126.7	126.9	124.5	135.2	107.5	111.9	122.1	115.0	153.9	128.6	151.9	93.2
Dec.....	126.1	127.2	127.4	124.9	135.6	108.4	111.7	119.2	115.2	154.4	129.1	152.9	93.2
1990: Jan.....	127.4	130.0	130.4	125.9	136.3	110.8	112.1	116.7	117.2	155.9	129.9	154.0	97.6
Feb.....	128.0	130.9	131.3	126.1	136.6	110.2	112.8	120.4	117.1	157.5	130.4	154.7	96.4
Mar.....	128.7	131.2	131.5	126.8	137.8	109.9	112.8	125.4	116.8	158.7	130.9	155.2	95.5
Apr.....	128.9	131.0	131.3	126.8	138.0	109.4	112.8	126.7	117.3	159.8	131.4	155.8	95.7
May.....	129.2	131.1	131.3	127.1	138.3	109.9	113.2	125.5	117.7	160.8	131.7	156.6	96.7
June.....	129.9	131.7	132.0	128.3	139.5	112.2	113.1	123.3	118.2	161.9	131.9	157.8	99.5
July.....	130.4	132.4	132.7	129.2	141.1	111.3	113.6	120.8	118.4	163.5	132.7	159.2	98.9
Aug.....	131.6	132.7	132.9	130.2	142.4	112.7	113.3	122.2	120.6	165.0	133.0	160.4	103.6
Sept.....	132.7	133.0	133.2	130.5	142.3	114.0	113.8	126.8	123.0	165.8	134.1	162.6	108.8
Oct.....	133.5	133.4	133.6	130.6	142.4	113.4	114.2	128.4	125.8	167.1	134.3	163.2	111.4
Nov.....	133.8	133.7	134.0	130.4	142.4	112.9	113.8	127.5	126.9	168.4	134.4	163.6	110.9
Dec.....	133.8	133.9	134.2	130.5	142.7	112.7	113.7	125.3	127.2	169.2	134.6	164.5	110.1

¹ Includes alcoholic beverages, not shown separately.

² See table B-59 for components.

³ See tables B-60 for definition and B-59 for components.

Note.—Data beginning 1978 are for all urban consumers; earlier data are for urban wage earners and clerical workers. Data beginning 1983 incorporate a rental equivalence measure for homeowners' costs and therefore are not strictly comparable with earlier figures.

Source: Department of Labor, Bureau of Labor Statistics.

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The demand for gasoline

Further evidence

Leonidas P. Drollas

Sufficient time must be allowed to elapse to assess fully the response of gasoline demand to price changes. Hitherto, empirical work on the subject has generally not examined the period beyond 1975; moreover, the extant time-series studies concentrate almost exclusively on the USA. This study extends both the observation period and the country coverage. A vehicle stock-adjustment model is estimated via its reduced form without explicit consideration of the vehicle stock itself. However, the estimation procedure incorporates the structure by way of constraints on the parameters. Cross-section analysis offers additional evidence concerning the truly long-run price elasticity. The results suggest that there is no need to resort to elaborate models to explain adequately gasoline demand. Gasoline demand exhibits a long-run price elasticity near unity with time lags exceeding six years, while there is tentative evidence that the duration of these lags is not fixed.

Keywords: Gasoline demand; Prices; Lags

Though gasoline has received in the empirical literature the amount of attention that befits its status in the family of oil products, most extant studies and models are based on data up to 1975 and are preoccupied with the USA, especially in a time-series context. This study seeks to redress the balance by examining the period to 1980 and encompassing certain European countries, in addition to the USA.

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The need to extend the estimation period to incorporate the years following the 1973/74 oil crisis is particularly strong, since one would not expect to see the full response to the very large price increases within a year or so of the crisis. Moreover, the gasoline markets were rocked by even more severe price increases in 1978/79 due to the Iranian Revolution, and the world is still adjusting to the price jumps set in motion then.

Lest it be thought, however, that this study represents merely an update of existing models, it should be emphasized at the outset that a new approach is used to examine gasoline consumption over time, an approach that is economical in its data requirements and parsimonious regarding estimated parameters, yet succeeds in achieving a high degree of explanatory power. The study also presents evidence regarding the truly long-run price elasticity of demand for gasoline, and examines – albeit cursorily – the possibility that the speed of adjustment in the dynamic time-series models may not be invariant over time.

The main messages that can be gleaned from the empirical analysis can be put succinctly as follows:

- most countries in the sample display similarities rather than dissimilarities;
- the long-run price elasticities of demand obtained from the time-series models suggest that although gasoline demand is price inelastic, it is not far from possessing unitary elasticity;
- there is some evidence from a cross-section model that the truly long-run price elasticity is well above unity;
- there appears to be considerable inertia in gasoline consumption due essentially to the slowly changing vehicle stock and habit persistence;
- there is tentative evidence that delays in the response of consumption vary a great deal in length over the years.

In terms of policy implications, the empirical results as they stand suggest that governments in gasoline consuming countries that tend to use taxes on gasoline as a source of revenue rather than, say, an instrument of energy conservation policy, will find the going increasingly tough in the long run — particularly if the price of crude oil keeps on rising inexorably. As far as the oil producing countries are concerned, the results would tend to imply that blind pursuit of oil price increases on the basis of inelastic demand for transport fuels cannot be relied upon to keep producing results in the longer term. Finally, these price elasticities suggest that the limit to the amount of refinery upgrading capacity needed may well be reached sooner rather than later.

Of models and elasticities

The various contributions in the literature are characterized ostensibly by their diversity: some models are based on simple dynamic relationships between gasoline consumption, the price of gasoline in real terms, and real income over time; others examine the variation of gasoline consumption per capita as a function of the price of gasoline, the stock of vehicles per capita, traffic density, real income per capita, etc. across countries in a particular year; still others incorporate elaborate vehicle-stock determining relationships in addition to examining the utilization rate of this stock.

I use the word 'ostensibly', because most of these models share a common logical foundation based on the self-evident idea that gasoline is consumed by way of an existing stock of vehicles; the differences between the models can then be ascribed essentially to the extent to which the models take into account explicitly the stock of vehicles and the factors affecting both the stock itself over time and its utilization rate.

Conceptually, the relationship between gasoline consumption and the vehicle stock is enshrined in the following identity:

$$G \equiv \sum_{i=1}^K \frac{MIL_i}{MPG_i} \quad (1)$$

where

G = total consumption of gasoline per time unit
 MIL_i = miles driven in the i th vehicle per time unit
 MPG_i = miles per gallon achieved by i th vehicle
 K = number of vehicles

Notice how the identity above — like all tautologies — is devoid of any real interest as it stands. However, if we assume à la Sweeney¹ that the vehicle population is segmented into vintages, each vintage representing a model year with certain characteristics shared by all vehicles of that year such as mileage driven and efficiency, we can derive a meaningful aggregate relationship as follows.

Writing,

$$G = \frac{MI_1 \cdot K_1}{mpg_1} + \frac{MI_2 \cdot K_2}{mpg_2} + \dots + \frac{MI_j \cdot K_j}{mpg_j} + \dots \quad (2)$$

where

MI_j = miles driven per vehicle per time unit in j th vintage

mpg_j = efficiency of j th vintage (in time unit considered)

K_j = number of vehicles in j th vintage

Multiplying (2) by $(MI \cdot K)/(MI \cdot K)$, where MI represents the average mileage driven per vehicle as far as the whole fleet is concerned and K is the total number of vehicles in existence, yields the following:

$$G = \left\{ \sum_{j=1}^J \frac{1}{mpg_j} \frac{(MI_j)(K_j)}{(MI)(K)} \right\} MI \cdot K \quad (3)$$

ie

$$G = \frac{MI}{MG} \cdot K \quad (4)$$

where

$$MG = 1 / \left\{ \sum_{j=1}^J \frac{1}{mpg_j} \frac{(MI_j)(K_j)}{(MI)(K)} \right\} \quad (5)$$

is a weighted harmonic mean of the efficiencies characterizing each vintage — in other words, a variable representing the average fuel efficiency of the whole vehicle population.

Furthermore, if we assume that the average distance driven within the time unit (for argument's sake, a year) is a function of the real price of gasoline among other influences — as indeed one can hypothesize about both the car stock itself and its average efficiency — Equation (4) is then transformed into the following behavioural equation:

$$G = \frac{MI(Pg^*)}{MG(Pg^*)} \cdot K(Pg^*) \quad (6)$$

where

Pg^* = real price of gasoline

(. .) = functions

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It is easy to see that Equation (6) above implies the following relationship between the various price elasticities of demand:

$$Eg \cdot p = Emi \cdot p - Emg \cdot p + Ek \cdot p \quad (7)$$

where

$Eg \cdot p$ = price elasticity of demand for gasoline

$Emi \cdot p$ = elasticity of response of distance to gasoline price

$Emg \cdot p$ = elasticity of response of efficiency to gasoline price

$Ek \cdot p$ = elasticity of vehicle stock to gasoline price

Thus, when the price of gasoline increases in real terms, a whole sequence of behavioural responses is set in motion, whereby people start to drive less, to drive these fewer miles more carefully, to exchange their less efficient vehicles for more efficient ones, and finally to own fewer vehicles than they would have done otherwise. The total effect of the real price increase on gasoline consumption is of course given by $Eg \cdot p$ in Equation (7) above.

Bearing in mind the microfoundations of gasoline consumption already presented, it is apposite at this stage to examine a few empirical results from studies of gasoline demand to be found in the literature. The list of results displayed in Table 1 is by no means exhaustive; however, it is hoped that most of the more important papers have been covered.

As mentioned in the introduction, there is an overwhelming bias in the literature — as can readily be seen from Table 1 — towards the USA. Hence, there are all kinds of models that have been estimated for the USA, ranging from the traditional time-series analysis of a simple gasoline demand equation incorporating a lagged dependent variable,² to single-equation pooled cross-section/time-series models,^{4,5} to multi-equation time-series models.^{3,11,13} The consensus view regarding the USA seems to be that the long-run price elasticity of demand lies around -0.80, while the long-run income elasticity is slightly below unity. As far as other countries are concerned, the limited evidence on offer suggests that they do not differ substantially from the USA. It is hoped that the following sections will prove to be of use in corroborating or refuting this consensus view.

Table 1. Price and income elasticities of demand for gasoline.

Study	Type, coverage	Price elasticity		Income elasticity	
		Short run	Long run	Short run	Long run
DRI, 1973, Ref 2	Time series, USA, 1950-73, lagged dependent variable	-0.07	-0.23	0.28	0.94
Oil Corporation, 1974, Ref 3	Time series, USA, 1950-73, separate equations for the components	-0.26	-0.78	0.18	0.88 ↑ Ownership
Houthakker <i>et al</i> , 1974, Ref 4	Dynamic pooled time series, USA, states, quarterly 1963-72	-0.075	-0.24	0.303	0.98
Charles River Associates, 1975, Ref 5	7-region pooled time series, USA, 1950-73	-0.28	-1.37	0.012	0.06
Houthakker and Kennedy, 1975, Ref 6	Logarithmic flow-adjustment, 12-OECD countries, 1962-72, cross-section/time-series	-0.47	-0.80	0.74	1.33
Ramsey <i>et al</i> , 1975, Ref 7	Time series, no dynamics, USA, private demand, annual 1947-70		-0.77		1.34
FEA, 1976, Ref 8	Time series, vehicle-miles (vm), aggregate, USA		-0.48		0.98
Sweeney, 1978, Ref 9	Time series, vehicle-miles (vm), USA, 1950-73	$Evm.p = -0.22$	$Emg.p = 0.72$ $Evm.p = -0.06$		0.82
Pindyck, 1979, Ref 10	Pooled 11 countries time series, 1955-73	$Ek.p = -0.26$ $Emg.p = 0.11$	$Ek.p = -0.64$ $Emg.p = 1.43$	$Emi.y = 0.06$ $Ek.y = 0.12$	$Emi.y = 0.66$ $Ek.y = 0.30$
Archibald and Gillingham, 1981, Ref 11	G, MI, MG equations, no K, USA, monthly data, 1972-74	1 car -0.77 2 car -0.22		1 car 0.29 2 car 0.56	
Wheaton, 1981, Ref 12	Cross national, 25 countries, 1972, no dynamics	$Eg.p = -0.78$ $Emi.p = -0.52$ $Emg.p = 0.32$ $Ek.p = 0.16$ (I)		$Eg.y = 1.20$ $Emi.y = 0.52$ $Emg.y = -0.19$ $Ek.y = 1.26$	
Fishelson, 1982, Ref 13	Time series G, MI, MG, K equations, 1960-78, dynamic, USA	-0.49	-0.98		

Is an explicit treatment of vehicles necessary?

Gasoline, along with most other fuels that are consumed to generate power, obviously needs a stock of vehicles or machinery (eg lawnmowers) to exist for consumption to be possible. This trite remark has to be made again at this juncture in order to draw a comparison between the treatment of, say, heating gas oil and gasoline. In the case of heating gas oil, no one seriously proposes counting the number of oil-fired boilers in existence in order to arrive at a stock figure, which in combination with a utilization rate would yield heating gas oil consumption. One has to try to explain gas oil consumption via some other route that obviates the need to know the exact number of boilers in existence. Why, then, do most gasoline studies lay so much emphasis on the vehicle stock and its technical characteristics?

The main reason seems to be a practical one. Vehicle stock data are available in most developed countries, unlike boiler stocks. Fiscal authorities consider the taxation of vehicles a matter of utmost importance and are prepared to go to extraordinary lengths to maintain registers of vehicles. Moreover, it all sounds so logical – given the number of vehicles, miles driven per vehicle, and the technical efficiency of each vehicle, gasoline consumption drops out by way of an identity! Or does it?

As we have seen above, the only *true* identity is the summation over K vehicles of miles driven – at a certain mpg – by the i th vehicle (Equation (1)). On the other hand, one can arrive at an equation with operational significance (see the derivation of Equation (4) above) by assuming that all vehicles fall into distinct vintages. However, one assumption made en route in the derivation, and another required to allow one to obtain in practice a weighted harmonic mean of efficiencies, conspire to cast a shadow over those studies that rely heavily on published vehicle fleet efficiencies and average miles driven. The first assumption – that all vehicles within a common vintage are driven the same number of miles per time unit and possess the same efficiency – is required to be able to segment the sample into vintages, while the second – that all vintages share a common number of miles driven (ie $MI_j = MI$ all j , in (5) above) – is required to obtain in practice a measure of vehicle fleet efficiency by weighting the estimated efficiencies of each vintage only by the share of each vintage in the total vehicle stock (ie K_j/K in (5)) and not by relative vehicle-miles. In fact, I am given to understand that the 'miles-travelled' statistics in the USA are obtained by calculating the average fleet efficiency in the manner suggested and then multiplying this efficiency figure by total gasoline consumption. A further practical complication in the case of the European countries considered is that efficiency statistics by vintage, and indeed the number of vehicles in each vintage, are not readily available.

Without wishing to denigrate the efforts of those authors who have made use of published miles-per-annum and mpg data, it is the contention of this paper that one need not resort to particularly elaborate equation systems based on such data to explain a high proportion

of the variation in gasoline consumption over time. Furthermore, one need not use vehicle stock data either.

The key to our understanding of the forces governing the consumption of gasoline over time lies in the behavioural functions associated with each of the elements mentioned above. In line with other studies, it is assumed that economic variables influence both the desired stock of vehicles and the utilization rate of this stock. However, unlike other studies, it is felt that one need not be specific about the vehicle stock and vehicle miles – algebraic substitution and constrained estimation usually suffice.

Bearing in mind the points made above, the relationship between the amount of gasoline consumed within say a year, the vehicle stock, and its utilization rate, can be written as:

$$G_t = U_t \cdot K_t$$

ie

$$\ln G_t = \ln U_t + \ln K_t \quad (8)$$

where U = utilization rate.

The utilization rate U incorporates both notional miles driven per annum and average efficiency, and is specified as a constant elasticity function of the real price of gasoline and real income, ie

$$\ln U_t = a_0 + a_1 \ln (Pg/P)_t + a_2 \ln Y_t \quad (9)$$

where

Pg = nominal price of gasoline

P = prices of all other goods

(NB $Pg_t^* = (Pg/P)_t$)

Y = real income

Note that the utilization rate is postulated to be a function of the real price of gasoline only, because it is assumed that the prices of rival forms of transport influence the decision to invest in gasoline-consuming vehicles rather than their utilization rate once they have been purchased (this assumption has been borne out empirically). Furthermore, note that the actual utilization rate (though unobservable) is postulated to equal the desired rate, ie Equation (9) represents an equilibrium relationship, which is not unreasonable given that we are dealing with an annual model.

The actual vehicle stock is assumed to adjust towards its desired level with a lag due to what has been termed 'habit persistence', but which in fact encompasses information, decision, and investment delays. These delays are typically considered to be the result of two antithetical forces: one, based on the cost of being out of equilibrium, forcing the pace of change, with the other, based on the cost involved in actual change, retarding change. Another way of looking at it is to assume that the actual vehicle stock at any moment is not determined solely by the current levels of certain relevant factors (eg real income, the price of vehicles, etc) but also by past levels of these factors, with the effect on the present of more remote periods being discounted more heavily than that of more recent periods. Viewed in this manner, the size of the existing vehicle stock in an extreme case

could owe more to developments some time ago than current conditions.

At any rate, whichever way one looks at it results in similar dynamic adjustment mechanisms in discrete time, if one does not take explicitly into consideration the error terms. For example, the widely used partial adjustment hypothesis or 'habit persistence' model referred to above yields a final equation virtually identical to an equation obtained by way of the second route that assumes the discounting of the past follows a pattern of geometric decay – the Koyck or geometric lag scheme. On the other hand, explicit consideration of error terms both introduces complications and affords us an admittedly convoluted way of distinguishing between the two schemes.*

Without losing sight altogether of certain underlying complexities connected with the error terms, our general ignorance regarding the true structure of the errors means in practice that we may proceed cautiously along simpler trails. Accordingly, comparatively little is lost and much gained by accepting the principle of delayed adjustment (or the intuitively equivalent principle of geometrically declining lag effects) and positing the following adjustment mechanism:

$$\ln K_t - \ln K_{t-1} = g(\ln K^* - \ln K_{t-1}) \quad (10)$$

where

K^* = desired vehicle stock

g = speed of adjustment ($0 < g < 1$)

The desired vehicle stock in turn is postulated to depend on the real price of vehicles, real income, and the relative price of gasoline with respect to the price of alternative forms of transport in real terms, ie

$$\ln K_t^* = b_0 + b_1 \ln (Pg^*/Pr)_t + b_2 \ln Y_t + b_3 \ln Pc_t \quad (11)$$

where

Pr = real price of transport services

Pc = real price of vehicles

By straightforward substitution and subsequent algebraic manipulation, it is possible to eliminate the unobservable utilization rate and the stock of vehicles. One is then left with a dynamic equation in terms of the consumption of gasoline and the predetermined variables, ie

$$\begin{aligned} \ln G_t = & (a_0 + b_0)g + (a_1 + gb_1) \ln Pg_t^* - gb_1 \ln Pr_t \\ & + (a_2 + gb_2) \ln Y_t + gb_3 \ln Pc_t \\ & - a_1(1-g) \ln Pg_{t-1}^* - a_2(1-g) \ln Y_{t-1} \\ & + (1-g) \ln G_{t-1} \end{aligned} \quad (12)$$

Estimation of the final-form equation above by way of any single-equation based estimation technique is acceptable if the main intention is to predict rather than obtain parameter estimates. However, if one's primary objective is to unravel the tangled web of relationships that result in Equation (12) without considering explicitly the vehicle stock, miles driven per

annum, etc, one needs to resort to a method of estimation that allows for parameter restriction during estimation.

Empirical results

The estimation technique used in the case of Equation (12) was Full Information Maximum Likelihood (FIML) with parameter restrictions within equations, while the actual programme used was RESIMUL, one out of a suite of programmes developed by C. R. Wymer¹⁵ to deal with parameter-constrained estimation, among other things. In this instance it might seem we are using a sledgehammer to crack a feeble nut. However, it is the very use of parameter-constrained FIML that allows us to obtain consistent parameter estimates of the implied structural model from the final form, because as the programme iterates on the parameter set to maximize the likelihood function, the constraints implied by the structure and enshrined in the equation to be estimated in the form of functions of parameters (eg $a_2 + gb_2$) are brought into play to limit the extent to which particular parameters can vary during the maximization procedure. There is another factor in favour of the use of FIML estimation when dealing with Koyck lags. As Morrison¹⁶ has shown, the methods that have given the best estimates of the parameters of the familiar geometric lag have involved numerical approximations to the maximum likelihood solution.

Before the main results of the estimation are presented, it is apposite to discuss briefly the vexed question of lag structures. The ubiquitous Koyck¹⁷ lag was used in the model presented above essentially because of its popularity and recognizability. However, there is no theoretical reason why the lag structure should follow a pattern of geometric decline. Indeed, early on in the history of lag schemes, Solow,¹⁸ Almon,¹⁹ and Jorgenson²⁰ all generalized the lag structure in such a way as to include the geometric lag as a special case of the general scheme.

Perhaps the best way to visualize the more general lag pattern put forward by these authors in juxtaposition to the Koyck lag is to consider Figure 1.

Imagine that the dependent variable in question – represented by "y" – is in equilibrium, which means that

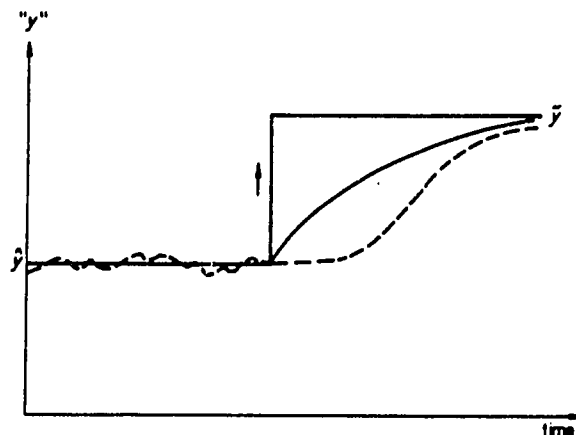


Figure 1. Delayed responses to a step change.

For details see pp 33–34 in Griliches, Ref 14.

it follows its desired level (given by "y") apart from a random variation around it. Then imagine that a change occurs in the behavioural function that determines the desired level and that this level increases. The geometric lag response of "y" would follow the solid line, while the alternative lag scheme would cause "y" to follow the dashed line. In the latter case, there is little response initially to the new desired level, then an accelerated response, and finally a slowing down as "y" approaches the new equilibrium. Many researchers have found the inverted-V lag† a more plausible lag structure since Solow introduced it in 1960. It is felt that people tend to delay their response until they are sure that the circumstances that led to the new desired level — such as a real price increase, in the case of a demand function — are likely to persist. Change is not costless, and people would be reluctant to invest, for example, in new more fuel-efficient equipment if they believed that an energy price increase in real terms is merely a temporary aberration due to particular conditions prevailing at the time.

At any rate, the Solow generalization can be written as follows in terms of the variables dealt with in this paper:

$$\ln K_t = \sum_{i=0}^{\infty} c_i \ln K_{t-i}^* \quad (13)$$

where

$$c_i = \binom{r+i-1}{i} (1-g)^r g^i \quad (14)$$

In other words, Solow postulated that the actual variable is a distributed lag function of its desired level in the current and all previous periods, the distributed lag scheme being represented by coefficients c_i that follow a Pascal distribution. It can be shown quite easily that the Solow scheme boils down to the geometric lag if r above equals unity. If, on the other hand, $r=2$, the Solow pattern becomes

$$\ln K_t = 2g \ln K_{t-1} - g^2 \ln K_{t-2} + (1-g)^2 \ln K_t^* \quad (15)$$

Incorporation of Equation (15) above into the system of equations we have been dealing with instead of Equation (10) yields the following final-form equation:

$$\begin{aligned} \ln G_t = & (a_0 + b_0)(1-g)^2 + (a_1 + b_1(1-g)^2) \ln Pg_t^* \\ & - (1-g)^2 b_1 \ln Pr_t + (a_2 + b_2(1-g)^2) \ln Y_t \\ & + (1-g)^2 b_3 \ln Pc_t - 2a_1 g \ln Pg_{t-1}^* \\ & - 2a_2 g \ln Y_{t-1} + a_1 g^2 \ln Pg_{t-2}^* + a_2 g^2 \ln Y_{t-2} \\ & + 2g \ln G_{t-1} - g^2 \ln G_{t-2} \end{aligned} \quad (16)$$

Equation (16) is merely a more elaborate version of the final form in the case of the geometric lag — Equation (12). The econometric arguments in favour of FIML estimation with parameter constraints that were vented

regarding geometric lags apply *a fortiori* in the case of inverted-V lags.

The most sensible course of action to take empirically is to remain sceptical as to whether the true lag scheme is a geometric or an inverted-V scheme, and estimate both formulations. This has been done for the five developed countries that had the requisite data sets readily available. The estimation results are presented in Table 2.

The first impression one gets looking at Table 2 is of similarity rather than diversity between the countries. One also soon observes that the differences between the two lag schemes are not striking in terms of the parameters they both yield. Detailed commentary on the results can be put succinctly as follows:

- The speed of adjustment‡ of gasoline demand to changed circumstances is slow, full adjustment taking more than 7 years. Moreover, the results suggest that the lag in consumption can be identified with the slowly changing vehicle stock. There is broad agreement on the speed of adjustment among countries.
- There is an identifiable short-run effect of the real price of gasoline on the demand for gasoline, which works principally through the utilization rate. Again, there are strong similarities between countries regarding the magnitude of this short-run price elasticity.
- As far as the effect of a change in the level of economic activity on the utilization rate is concerned (ie parameter a_2), the empirical work drew a blank apart from the USA. William Wheaton¹² provides an unsolicited explanation for this, since he found that increases in income do lead to more miles driven, but the increases in income also lead to more vehicles (per capita), and more vehicles per capita tend to lead to fewer miles driven per vehicle. Our formulation does not allow for these opposing effects explicitly, and logic dictates that the results would be particularly inconclusive in countries with a rapidly increasing vehicle stock per capita (most European countries would fit this bill in the post-WWII period in contrast to the USA).
- The long-run income effect on gasoline demand operates through the effect of income or activity on the desired vehicle stock (parameter b_2). The evidence from the estimation is overwhelmingly in favour of unitary elasticity as far as the European countries are concerned. In the USA, it appears that vehicles are considered necessities (b_2 well below unity — in fact, not significantly different from zero). This latter point seems to accord well with the role of the private automobile in the American way of life.
- There is some evidence of an effect of the price of vehicles on gasoline demand via its effect on the vehicle stock (UK, France, USA). However, this effect is relatively small and takes a long time to influence demand.

†The lag scheme owes its description as such to the plot of the derivative, which resembles an inverted-V in that it first rises, reaches a peak, and then falls away.

‡The speed of adjustment parameter g can be reinterpreted in terms of the time taken for 90% of adjustment of the actual to the desired level to occur. Thus, $(2.3/g)$ and $(4/g)$ yield the time in years for the Koyck and inverted-V models respectively.

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Table 2. Final form of gasoline demand model based on vehicle stock adjustment.

Country/model	g	a_1	a_2	b_1	b_2	b_3	Price elasticity		Years for 90% adjustment	Root mean square % error	χ^2 (DF)	\bar{R}^2
							Short run	Long run				
UK:	0.23	-0.20	-0.08 ^a	-0.35	1.29	-0.65	-0.28	-0.55	10	1.75	2.6	0.9989
geometric lag	(3.8)	(3.2)	(5.6)	(1.6)	(4.5)	(3.4)	(5.9)	(2.8)			(2)	
UK:	0.62	-0.17	-0.08 ^a	-0.45	0.98	-0.56	-0.24	-0.62	7	1.57	17.4	0.9991
inverted-V lag	(8.2)	(3.4)	(7.2)	(1.7)	(2.7)	(2.3)	(4.9)	(2.2)			(6)	
W. Germany:	0.35	-0.19		-0.62	1.15	-0.56	-0.41	-0.82	7	1.97	0.29	0.9995
geometric lag	(3.0)	(1.5)		(3.5)	(8.5)	(0.9)	(5.8)	(5.5)			(1)	
W. Germany:	0.46	-0.25		-0.95	1.07	-0.88	-0.53	-1.20	9	2.08	5.4	0.9993
inverted-V lag	(5.3)	(2.0)		(2.8)	(6.3)	(1.4)	(7.6)	(4.4)			(3)	
France:	0.24	-0.39		-0.19	1.08	-0.44	-0.44	-0.58	10	1.08	0.001	0.9996
geometric lag	(3.4)	(8.5)		(1.3)	(15.1)	(3.3)	(12.2)	(4.8)			(1)	
USA:	0.23	-0.24	0.55	-0.48 ^b	0.34	-0.64	-0.35	-0.73	10	1.10	1.1	0.9987
geometric lag	(3.4)	(3.7)	(2.8)	(2.0)	(1.5)	(2.8)	(9.4)	(3.6)			(1)	
USA:	0.61	-0.24	0.72	-0.46 ^b	0.21	-0.51	-0.32	-0.70	7	0.97	4.81	0.9989
inverted-V lag	(8.1)	(5.6)	(5.2)	(2.1)	(1.3)	(2.1)	(8.5)	(3.6)			(3)	
Austria:	0.39	-0.34	0.35	-0.48	1.02	-0.34	-0.52	-0.82	6	2.07	1.8	0.9989
geometric lag	(4.0)	(2.9)	(0.7)	(4.8)	(2.2)	(1.1)	(6.9)	(9.5)			(1)	
Austria:	0.45	-0.43		-0.47	1.39	-0.42	-0.57	-0.89	9	2.06	19.3	0.9987
inverted-V lag	(4.4)	(3.8)		(4.2)	(11.9)	(1.1)	(7.8)	(7.8)			(3)	

Notes:

Estimation covers period 1950–1980. Method of estimation is FIML with non-linear parameter restrictions. χ^2 test with indicated degrees of freedom (DF) examines the appropriateness of the over-identifying parameter restrictions. t values in parentheses.

^a Dummy variable used to capture effect of Suez crisis.

^b Real price of gasoline used in vehicle stock equation.

- The one quantity of prime importance to oil producers, oil companies, and governments in oil-consuming countries is the long-run price elasticity of demand for gasoline. Table 2 shows that the estimates are certainly above -0.5 , and in the case of West Germany, Austria and the USA, the estimates are not statistically significantly different from unity. Of the two components that make up the long-run elasticity (a_1 and b_1), the effect of the price of gasoline on the vehicle stock is dominant in all cases.
- On the whole, the two lag formulations yield parameters that are statistically indistinguishable, apart that is from West Germany's b_1 , Austria's a_1 , and the USA's a_2 . Naturally, the speeds of adjustment cannot be tested for equality, because they have differing interpretations (eg if both lag formulations imply a 10 year lag for 90% adjustment, then the geometric-lag speed of adjustment parameter will have the value 0.23 whereas the inverted-V will be 0.4).
- The explanatory power of these single-equation final form models is quite high, as can be ascertained from their low RMSEs (Root Mean Square Errors). Furthermore, in most cases the χ^2 test is passed, implying that the parameter restrictions imposed on the models are valid, ie the underlying structure is as specified.

Further results: five more countries and a variable speed model

Before examining the likely magnitude of the price elasticity of demand for gasoline in the really long run,

it is apposite to present the results of two further bits of analysis pertinent to the time-series models examined so far. Table 3 contains the results from estimating a conventional partial adjustment model[§] of gasoline demand, based on a geometric lag mechanism from Equation (10), for a further five European countries over the period 1955–80. The reason why simple lag models have been estimated in this case is because it was not possible to obtain satisfactory data for series such as the price of vehicles and the price of public transport in these countries.

The salient features of this analysis can be stated simply as follows. First, though the estimated long-run price elasticities appear in most cases – except Sweden – to be well above unity, they are not statistically significantly different from unity. The previous point applies equally to the income elasticity of demand – except for Belgium and Sweden. The lags implied by the speeds of adjustment are broadly similar across this small sample of countries. The RMSEs are of the same magnitude and uniformly higher than the corresponding errors in the more complete models presented before. Since the countries for which full data sets exist yielded better results in the case of the implied vehicle stock model than the elementary partial adjustment model, there is every reason to believe that this would have been

[§]This model is written

$$\ln G_t - \ln G_{t-1} = k(\ln G_t^* - \ln G_{t-1})$$

where the desired level of gasoline demand G^* is given by

$$\ln G_t^* = c_0 + c_1 \ln P g_t^* + c_2 \ln Y_t$$

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Table 3. Simple lag models of gasoline.

Country/model	Price		Income		Years 90%	χ^2 (DF)	Root mean square (%)
	Short run	Long run	Short run	Long run			
Belgium:							
geometric lag	-0.48 (4.7)	-1.62 ^a (2.3)	0.38 (1.7)	1.27 (9.1)	8	0.0 (0)	3.2
inverted-V lag	-0.50 (4.4)	-1.17 ^a (3.7)	0.57 (2.9)	1.34 (16.7)	11	3.7 (1)	3.5
Italy:							
geometric lag	-0.41 (4.6)	-1.08 ^a (5.7)	0.31 (2.4)	1.34 ^a (7.1)	10	0.0 (0)	4.4
inverted-V lag	-0.38 (3.6)	-1.44 ^a (6.2)	0.39 (3.1)	1.46 (11.5)	8	3.5 (1)	4.6
Netherlands:							
inverted-V lag	-0.29 (1.3)	-1.81 ^a (1.3)	0.18 (1.6)	1.11 ^a (4.1)	7	2.1 (1)	4.6
Sweden:							
geometric lag	-0.17 (2.7)	-0.52 (2.0)	0.46 (2.6)	1.46 (11.7)	7	0.0 (0)	2.3
inverted-V lag	-0.16 (2.5)	-0.37 (2.1)	0.65 (3.6)	1.50 (20.3)	12	2.1 (1)	2.3
Denmark:							
geometric lag	-0.38 (2.8)	-1.07 ^a (3.4)	0.31 (1.6)	0.86 (3.3)	6	0.0 (0)	4.4
inverted-V lag	-0.31 (2.9)	-1.27 ^a (3.0)	0.14 (1.1)	0.57 ^a (1.6)	8	1.6 (1)	3.8

Notes:

Method of estimation is FIML with parameter restrictions within the equation. χ^2 test with indicated degrees of freedom (DF) examines the appropriateness of the over-identifying parameter restrictions. t values in parentheses.

^a Indicates parameters that are not statistically significantly different from unity.

the case had one been able to obtain the relevant series for the second set of countries as well.

The second bit of analysis is potentially of great importance, if it proves to be relevant in the case of other countries also. The USA has been used as a test bed in this section more in the spirit of a 'scouting party' than an 'armoured column'. At issue is whether the speed of adjustment of the vehicle stock (see Equation (10)), which has been assumed to be constant, is in fact variable. As both Feige²¹ and Griliches¹⁴ have shown, the partial adjustment scheme exemplified by Equation (10) can be derived from the minimization of a quadratic cost function that combines the cost of being out of equilibrium with the cost of adjusting towards the new equilibrium. The interesting result from our point of view is that the mean time lag implied by the partial adjustment scheme is a function of the two costs, ie

$$\text{Mean time lag} = \frac{1-g}{g} = \frac{B}{A} \quad (17)$$

where

B = cost of adjusting

A = cost of being out of equilibrium

Now, if one (or both) of the costs are not constant, but depend on some other variable — for example, the cost of adjusting may depend on the rate of interest, while

the cost of being out of equilibrium may depend on the magnitude of the disequilibrium itself — the speed of adjustment will vary over time.

The main factor leading to a variable speed in the case of the gasoline models based on the partial adjustment scheme over the period examined would in all probability be the real price of gasoline, the only variable that changed dramatically during the sample period. Therefore, it has been assumed that the speed of adjustment in the USA case is a function of the real price of gasoline, thus

$$g_t = m_0 + m_1 \ln Pg_t^* \quad (18)$$

Substitution of Equation (18) in the final-form Equation (12) above yields the following estimating equation:

$$\begin{aligned} \ln G_t = & m_0(a_0 + b_0) + (a_1 + m_0b_1 + (a_0 + b_0)m_1) \ln Pg_t^* \\ & + (a_2 + m_0b_2) \ln Y_t - a_1(1 - m_0) \ln Pg_{t-1}^* \\ & - a_2(1 - m_0) \ln Y_{t-1} + m_1b_1(\ln Pg_t^*)^2 \\ & + m_1b_2(\ln Pg_t^* \ln Y_t) - m_1(\ln Pg_t^* \ln G_{t-1}) \\ & + a_1m_1(\ln Pg_t^* \ln Pg_{t-1}^*) + a_2m_1(\ln Pg_t^* \ln Y_{t-1}) \\ & + (1 - m_0) \ln G_{t-1} \end{aligned} \quad (19)$$

◆Note that Equation (12) as estimated for the USA does not have a real price of transport in the desired vehicle stock equation, as this was not found to be statistically significant.

It is immediately apparent that Equation (19) is non-linear in the variables, as indeed it might be apparent that with $m_1 = 0$, Equation (19) boils down to the familiar Equation (12). Non-linear estimation would normally present estimation problems in a simultaneous equation context. However, in this case we have to deal only with a single equation, which means that the right-hand-side variables can be constructed independently and treated as normal regressors. The implicit structure is embodied in the relationship between the parameters, as we encountered in the case of Equation (12), and all appears to be plain sailing. However, perils lurk just beneath the surface in the form of a parameter identification problem. The parameters concerned are m_0 and the combination $a_0 + b_0$ (which cannot be separated into a_0 and b_0 and must therefore always be estimated as a sum). Attention is drawn to the fact that m_0 and $(a_0 + b_0)$ appear both as a weighted sum and a product, ie

$$\begin{aligned} a_1 + b_1 m_0 + m_1 (a_0 + b_0) &= K_1 \\ m_0 (a_0 + b_0) &= K_2 \end{aligned} \quad (20)$$

where the other parameters are all identifiable. Thus, m_0 and $(a_0 + b_0)$ are the roots of a quadratic equation, and the estimation procedure cannot distinguish between the two. All is not lost, however, if we could only obtain an independent estimate of either m_0 or $(a_0 + b_0)$, for then we can iterate between the two parameters by treating one of them as a constant, estimating the other, then treating that as a constant and estimating the first as a parameter, and so on until the parameters converge to stable values. Fortunately, we have an initial value for $(a_0 + b_0)$ from our prior estimation of Equation (12), and it is this value (12.26) that serves as the starting point.

It took only seven iterations for the parameters m_0 and $(a_0 + b_0)$ to converge to values that changed by only 0.4% and 0.03% respectively. The full results of the final iteration are presented in Table 4.

There is reasonably strong evidence that the speed of adjustment is indeed variable, with an average value over the sample period of 0.225 (90% adjustment in 9 years) based on the sample mean of the real price of gasoline. It is interesting to see how close these parameters are to those estimated in the constant-speed case, which seems to suggest that estimation of geometric lag models with *constant* speeds of adjustment is likely to yield long-run parameters that are similar

Table 4. Variable speed of adjustment, USA.

$m_0 =$	-1.885 (1.53)
$m_1 =$	0.533 (40.53)
$a_1 =$	-0.223 (3.58)
$a_2 =$	0.562 (2.99)
$b_1 =$	-0.532 (3.66)
$b_2 =$	0.370 (1.77)
$b_3 =$	-0.617 (3.05)

Note:

t values are in parentheses; RMSE = 1.04%; $\bar{R}^2 = 0.9968$.

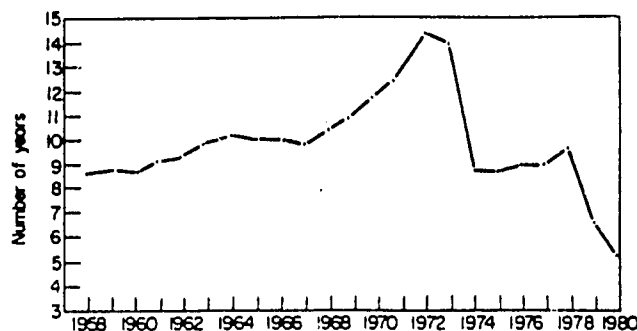


Figure 2. Speeds of adjustment for gasoline in the USA (time taken for 90% adjustment).

to those obtainable from a variable speed model such as the one above, but an adjustment-speed parameter that is an *average* over the sample period. Incidentally, an increased speed of adjustment of the vehicle stock to its desired level due to a higher real gasoline price is compatible with the observed increase in the median age of the US auto fleet since the early 1970s. Stagnating real income and higher real gasoline prices combine to reduce the desired vehicle stock from the level it would otherwise have attained had income and prices followed their 1960s trends, while increased real gasoline prices speed up this process. A lower vehicle stock than would have existed otherwise implies fewer *net* additions to the stock and thus an 'aging' of this stock compare with the earlier period, exactly as the population 'ages' when the birth rate slows down.

The way in which the speed of adjustment varies over time as a function of the real price of gasoline is the prominent feature of this analysis. As can be seen in Figure 2, the time taken for 90% adjustment rose steadily in the 1950s as the price of gasoline fell in real terms, falling subsequently in two large jumps to a 1980 value of 5 years, which is certainly rapid by historical standards. If the speed of adjustment, as indicated by the USA model, is capable of increasing so rapidly, then models based on constant speeds of adjustment might yield biased forecasts in periods when the price of gasoline is increasing by leaps and bounds. One can only say at this stage that variable speeds of adjustment ought to be looked at more closely.

In the really long run . . .

In the long run we shall all be dead, as Keynes so aptly put it. Of course, he was being facetious, to goad his contemporaries into action, fearing that a preoccupation with the future consequences of action (or inaction) might jeopardize one's chances of ever getting there. Is there a need then to consider the demand for gasoline in the very long run, or should we take refuge in Keynes' *bon mot* and let our successors worry about it?

The nature of oil as an exhaustible resource precludes it from being treated like any other good. Arguments about the efficient use of exhaustible resources dictate that demand should be channelled into premium uses, ie where the price elasticity of demand is inelastic in

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the longer term. Conventional wisdom has it that the demand for the heavier fractions of the barrel is price elastic due to the presence of substitutes (for example, the use of coal, natural gas, and nuclear fuel in power generation) unlike the demand for transport fuels. Therefore, the use of limited oil resources in activities that could use other fuels – fossil or otherwise – might be viewed with disdain, particularly by the oil producers who might feel that their precious asset is being wasted in non-premium uses.

The rights and wrongs of these views notwithstanding, there is a need to examine the factual premises upon which the thrust of such arguments is based – in particular, the extent to which the demand for transport fuels is in fact inelastic in the long run. The evidence gleaned so far from our time-series models tends to show that on the whole the long-run price elasticity of demand for gasoline is not significantly different from unity. The crucial question remains whether this price elasticity could be greater than unity!

To ascertain the magnitude of the long-run price elasticity of demand, we need to identify the long-run demand curve. This in turn can only be done – as far as an individual country is concerned – by observing a single country over a long enough period, so that different supply conditions, leading to variations in price, can trace out the demand curve. The critics of time-series models contend that an individual country cannot supply a long enough history of gasoline price variation, especially if one includes the decades of the 1950s and 1960s, to enable one to identify the long-run demand curve. What do they suggest instead?

It is felt that there is sufficient variation in the price of gasoline between countries (due mainly to different levels of taxation) to make cross-section analysis the preferred route to take in search of the elusive long-run price elasticity of demand. It is possible in principle to utilize variations across countries to obtain estimates of long-run price and income elasticities, provided one assumes that the underlying economic structure encapsulated in the parameters is invariant with respect to both time and the particular countries forming the group. Of course, these assumptions are not always justifiable, given that elasticities might vary over time and countries will almost certainly differ in terms of the structure of gasoline demand. The first assumption can be tested by estimating the cross-section model at various points in time. The second assumption can be dealt with in two ways: either by using country-specific dummy variables (with a concomitant increase in the number of years considered in order to obtain the requisite degrees of freedom), or by specifying a multi-equation model to account for the special factors representing the intercountry structural differences. In practice, the preferred route has been to include dummy variables and increase the number of observations by estimating 'pooled' time-series and cross-section models. In our case, the 'pooled' approach has been eschewed in favour of the classical cross-section study.

Relevant data covering 37 countries for the year 1977 have been collected in an attempt to estimate a simplified

Table 5. Cross-section data, 1977.

Country	Consumption per head (gallons)	Cars per thousand ^a	National income per head (SDRs) ^b	Price per gallon (SDRs) ^b
USA	451	525	6484.9	0.59
Canada	309	408	6011.3	0.65
Australia	223	394	5425.5	0.71
Sweden	172	346	6607.6	1.41
New Zealand	149	384	3662.0	1.14
Switzerland	122	305	8877.5	1.72
Iceland	115	316	5520.9	1.64
West Germany	103	333	6769.2	1.82
Denmark	97	271	7072.9	1.77
Great Britain	95	261	3642.9	1.14
France	93	319	5527.4	1.73
Belgium	92	292	6666.5	1.73
Austria	89	263	5055.9	1.64
Norway	84	274	6193.2	1.96
Netherlands	81	282	6171.7	1.73
Ireland	81	179	2428.4	1.45
Finland	79	227	4661.9	1.64
Japan	61	173	4871.5	1.73
Italy	54	289	2827.5	2.14
Cyprus	42	112	1432.4	1.27
Spain	39	162	2238.8	1.27
Brazil	37	58	995.4	1.18
Greece	36	67	2319.8	1.68
Chile	35	28	777.1	1.14
Jordan	30	25	737.3	1.09
Colombia	29	14	527.2	0.23
Portugal	22	101	1295.8	1.75
Turkey	14	13	855.3	1.05
Ethiopia	12	1	87.4	0.68
Thailand	10	8	321.0	0.77
Kenya	6	7	264.6	1.27
Tunisia	4	19	670.8	1.55
Sierra Leone	3	8	169.9	1.18
Sri Lanka	2.4	7	112.1	0.68
Malaysia (W)	2.3	52	893.3	1.18
Niger	1.4	2.2	120.0	1.46
Malawi	0.4	2	131.2	0.64

Sources: Gasoline and vehicle data from International Road Federation, *World Road Statistics 1974-78*, 1979 edition. National income and population data from IMF, *International Statistics*, various issues.

Notes:

^a 'Cars per thousand' refer to the total population.
^b Special Drawing Rights. An SDR is an artificial unit of currency created by the IMF based on a basket of currencies suitably weighted. Each national currency can be expressed in terms of SDRs; the conversions have been performed by the IMF.

cross-sectional model of gasoline consumption per capita based on this sample. The sample is quite representative, including highly developed countries along with extremely poor countries. Moreover, a particular subset of 24 countries has been used in a two-equation model of gasoline consumption per head and cars per thousand people. The models presented below must be considered as first attempts at cross-sectional analysis; further analysis will be required to improve the accuracy of the estimates. The most important cross-section data are presented in Table 5.

It is obvious from a cursory glance at the data that consumption of gasoline per capita is strongly correlated

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with the number of cars per head, which in turn is correlated with national income per capita. However, there are some interesting cases that stand out. Italy exhibits low gasoline consumption per capita in relation to its car population, while Colombia shows an excessive level of consumption per head in relation both to its car population and its income per head. Other cases of interest are Australia and New Zealand, both with roughly comparable car populations per head but differing gasoline consumption levels, and West Germany and Sweden with comparable car populations and income levels but quite different levels of gasoline consumption per capita. Almost all these cases have a common factor, varying gasoline prices, which accounts quite neatly for the discrepancies in gasoline consumption.

The first bit of cross-section analysis that can be performed is to regress gasoline consumption per capita against the price of gasoline and the car population per capita. The result was as follows (*t* values in parentheses):

$$\ln G_i = 0.07 - 0.79 \ln Pg_i + 0.87 \ln C_i \quad (21)$$

(2.6) (11.3)

where

$$\bar{R}^2 = 0.89 \text{ DF} = 34 \text{ mean square error} = 0.7467$$

G_i = gasoline consumption (gallons) per capita in *i*th country
 Pg_i = price of gasoline (SDRs per gallon)
 C_i = cars per thousand

A slightly higher long-run price elasticity of demand for gasoline was obtained by regressing gasoline consumption per capita against the price of gasoline and national income per head, ie

$$\ln G_i = 4.66 - 0.91 \ln Pg_i + 1.13 \ln Y_i \quad (22)$$

(3.2) (12.4)

$$\bar{R}^2 = 0.91 \text{ DF} = 34 \text{ mean square error} = 0.6926$$

In this case, national income per capita acts as a proxy for the car population per head. However, when both income per capita and car population per head are included in the regression, then the problem of multicollinearity becomes severe, as can be seen below:

$$\ln G_i = 3.51 - 0.90 \ln Pg_i + 0.83 \ln Y_i + 0.24 \ln C_i \quad (23)$$

(3.2) (2.5) (0.9)

$$\bar{R}^2 = 0.91 \text{ DF} = 33 \text{ mean square error} = 0.6938$$

In this equation, the strong correlation we know exists between car population per capita and income per head has resulted in less precise estimates of the separate effects of income and car population on gasoline consumption. Since we believe that both these explanatory variables have an effect on gasoline consumption, but know that these effects cannot be gleaned from the simple formulation due to multicollinearity, the answer appears to lie in the direction of a more complete specification of the relationships between income, car population, price of gasoline, and consumption of gasoline. A two-equation model

can be formulated to capture the essence of these relationships, as follows:

$$\begin{aligned} \ln C_i &= a_0 + a_1 \ln Pcar_i + a_2 \ln Y_i \\ \ln G_i &= b_0 + b_1 \ln Pg_i + \ln C_i \end{aligned} \quad (24)$$

In this recursive system of equations, the car population per capita is specified as a function of the price of cars and national income per capita, while gasoline consumption per capita is postulated to depend on the price of gasoline (the main variable affecting the utilization rate) and the stock of cars per capita. One is able to avoid the problem of multicollinearity by specifying a separate equation for the car stock in terms of income per head and the price of cars. From a practical point of view, the price of cars presents considerable difficulties, because it is well nigh impossible to obtain reliable data on a comparable basis for such a wide spectrum of countries. We have resorted to the use of a proxy for the price of cars in the form of taxes on acquisition and ownership of cars, but this was possible only for 24 countries out of the sample of 37.

The recursiveness of the equation system given by Equation (24) calls for estimation via a sequential use of ordinary least squares (OLS). Thus, the first equation is estimated using OLS (since the regressors are truly independent) and the predicted values of the dependent variable are subsequently used to form the regressor $\ln \hat{C}_i$ in the second equation, which is also estimated via OLS. The results of the estimation, with *t* values in parentheses, are as follows:

$$\begin{aligned} \ln C_i &= -5.1 - 0.4 \ln Pcar_i + 1.2 \ln Y_i \\ &\quad (7.8) \quad (3.0) \quad (16.2) \\ \bar{R}^2 &= 0.922 \quad \text{SEE} = 0.44 \\ \ln G_i &= -0.4 - 1.3 \ln Pg_i + \ln \hat{C}_i \\ &\quad (2.4) \quad (3.5) \\ \bar{R}^2 &= 0.322 \quad \text{SEE} = 0.611 \end{aligned} \quad (25)$$

The results seem to confirm our initial suspicion that multicollinearity was indeed a severe problem in the single-equation model above. The two-equation model yields sensible parameters that are statistically significant and have the anticipated signs. Moreover, the long-run price elasticity of demand for gasoline is higher than the equivalent single-equation estimates, while the long-run income elasticity of demand for cars suggests that the cars are 'luxury' goods. This last result is questionable as far as developed countries are concerned, given the role of saturation in car ownership at high income levels, but is quite plausible in a wider sample. Our proxy variable for the price of cars appears to have performed well, while the long-run price elasticity of demand for gasoline, at -1.3 , suggests that gasoline demand is price elastic in the long run, though on a purely statistical basis, the elasticity is not significantly different from unity. The cross-section analysis provides further tentative evidence of the elastic nature of gasoline demand with respect to price in the long run, in addition to the evidence gleaned from some of the time-series country models estimated (see Table 2).

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Conclusions

Of all the petroleum products, gasoline occupies today a position of pre-eminence due to its alleged price inelasticity of demand. Oil companies pursue gasoline sales because it is thought that gasoline represents the part of the crude oil barrel that is likely to suffer least from the ravages of crude oil price increases. Governments in oil-consuming countries load taxes on gasoline because it is thought to be a 'reliable' way of raising funds. Oil producer governments probably consider the transport sector to be the only one with a worthwhile claim on their wasting asset. In fact, all three actors on the oil stage share a common belief in the price inelasticity of demand for gasoline, both in the short and the long run.

While nobody would dispute that gasoline demand is inelastic in the short run (a year or two), this study casts doubts on the notion that it is so in the long run as well. The econometric results based on the time-series models suggest that the long-run price elasticity is not significantly different from unity in most cases, while the evidence – albeit tentative – from the cross-section model is that the truly long-run elasticity may well be above unity.

As has been demonstrated, there is no real need to resort to elaborate models involving *explicitly* the changing stock of vehicles, its efficiency, and its use. Once due care and attention is paid to the special characteristics of gasoline demand, it is possible to determine what affects gasoline consumption, and track its course with a reasonable degree of accuracy, by employing an estimation technique that incorporates the implicit structure via restrictions on the parameters of the model. As a result of the use of this technique, the considerable inertia that gasoline consumption seems to possess is identified with lags in adjustment of the vehicle stock to its desired level. Moreover, as an experimental model for the USA would have it, there is some evidence that the duration of these lags is not fixed. Indeed, if one assumes that the speed of adjustment is a function of the real price of gasoline, the US case implies that the time lag has more than halved in the decade of the 1970s following the substantial real gasoline price increases. If these results are corroborated as far as other countries are concerned, the responsiveness of gasoline demand to changes in the real gasoline price is even greater than assumed generally, with of course even more profound consequences.

It cannot be emphasized too strongly that if the price elasticity of demand is well above unity in the long run and consumers do speed up their reactions to changed circumstances, then the oil companies – with investment plans to increase their ability to extract more of the lighter products from crude oil – and governments – with their policy of taxing gasoline heavily – and oil producers – with their belief that their precious asset should be reserved for 'premium' uses – could be in for a rude shock. The simple explanation for the higher than expected price elasticity of demand for gasoline is threefold: there are substitute types of transport fuels

(diesel, liquified petroleum gas), there are substitute forms of transport, and of course consumers can spend their funds on activities or goods that compete with transport. Indeed, very few commodities are truly indispensable – given a long enough timespan, there are substitutes for most things.

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The long-run structure of transportation and gasoline demand

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This article reports estimates of a cross national model for automobile ownership, fleet fuel efficiency, driving per vehicle, and as derived from these three, gasoline consumption. The model is a recursive system of equations derived by aggregating individual behavioral equations for the choice of a durable good and its usage. The results suggest that across countries, gasoline price differences exert themselves primarily by affecting the amount of driving, and not as time series studies show, through fleet fuel efficiency. The estimates also suggest that gasoline consumption is much more income elastic than it was previously thought to be and that most of this income effect derives from the impact of income on auto ownership.

1. Introduction

■ In the years since the 1973 oil embargo, there have been a growing number of efforts to model the demand for gasoline and its relationship to the underlying demand for transportation services. Such efforts are useful not only in forecasting the market response to rising fuel prices, but also as policy tools to evaluate the impact of regulations, such as Federal Fuel Efficiency standards. With only a few exceptions, all of these efforts have used time-series data for the preembargo period (1947–1972), primarily in the United States (CRA, 1975; DRI, 1973; Sweeney, 1978; Pindyck, 1979; Wildhorn *et al.*, 1974).

The reliance on time-series data raises two important questions about the accuracy and reliability of the results of these models. First, during the preembargo period, real income rose slowly and real fuel prices fell gradually in a manner that was highly correlated. Can the models, therefore, separately estimate income and price effects? Second, during this same period, there was little absolute change in the real price of gasoline. Can such models, therefore, be relied upon to forecast truly long-run responses to major changes in price or income?

An alternative approach to estimating models of the demand for gasoline and transportation services is to introduce some cross sectional variation into the sample data. If, for example, one includes subarea disaggregation within the United States, income variation is obtained which is largely independent of fuel prices. The latter, however, will still exhibit little absolute variation. In fact, to get large scale price variation during the preembargo period, one must compare different countries. Unfortunately, the cross national studies (Houthakker and Kennedy, 1979) and the cross state studies within the United States (Greene 1979) use reduced-form models in which gasoline demand is predicted directly with no consideration of transportation services. The strength of the time-series models is that they estimate separate income and price effects for vehicle ownership, vehicle characteristics, and vehicle usage. Gasoline demand is then derived from a well-known identity relating these three components.

It is interesting that neither group of studies has investigated the possibility that structural relationships might exist among the different transportation components (own-

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ership, driving, vehicle efficiency). The cross sectional models estimate only the demand for gasoline, and although the time-series models have developed equations for each transportation component, the equations contain only exogenous variables, such as income and prices. A full structural model would permit inferences about the impact that regulating one endogenous variable (for example, fuel efficiency) would have on the others.

The objective of this study, then, is to improve upon this research in the ways discussed above. First, a long-run model will be estimated, cross nationally, to obtain parameters for a sample with maximum independent variation in income and prices. Second, the model will also be structurally disaggregated, not only to predict separately vehicle ownership, driving, and fuel efficiency, but also to make some preliminary assessments about possible relationships among these endogenous variables.

The results of the model contrast with the previous research in several important ways. The aggregate gasoline consumption elasticities are reasonably comparable, but the structure of demand differs considerably. The time-series studies suggest that in the long run the impact of price occurs mostly through improved fuel efficiency (smaller cars) and, to a lesser degree, lower ownership rates. The cross national estimates say quite the contrary, that in the long run most of the overall price elasticity comes from reduced usage of each vehicle. The results also suggest (for the first time) that ownership rates have a strong influence on vehicle usage, but fuel efficiency does not. Finally, the cross national model estimates include some highly elastic income effects, which indicate that reductions in aggregate fuel demand may be difficult, particularly in rapidly growing Third World countries.

As a note of caution, it would be prudent to point out that as is typical with most cross national research, the quality of the data used in the study is less than ideal. The results of the model, therefore, should perhaps be regarded more as pedagogical than definitive: cross national models can be estimated, and the estimates yield conclusions that seem to differ from those of models estimated using intracountry time series.

The article is organized as follows. Section 2 discusses the specification of the model and reviews some studies from the existing time-series literature. Section 3 discusses the data, and Section 4 presents a number of statistical results. Finally, Section 5 examines some implications of the research.

2. The derived demand for gasoline

■ Almost all time-series models of gasoline consumption estimate a derived demand equation by using an identity, such as (1):

$$CON = (AUTO \times DIST)/MPG, \quad (1)$$

where

CON = consumption of fuel per capita;

$AUTO$ = vehicles or automobiles per capita;

$DIST$ = use of each vehicle (miles per year); and

MPG = average fleet fuel efficiency.

With this identity, demand equations are estimated separately for each component ($AUTO$, $DIST$, MPG), and then overall fuel consumption is derived by applying the identity. Since (1) is log linear, any elasticity of CON is simply the sum of the three component elasticities. Thus, with respect to gasoline price (P), the following relationship applies:

$$E_{CON,P} = E_{AUTO,P} + E_{DIST,P} - E_{MPG,P}. \quad (2)$$

There are a number of advantages to estimating component demand equations, and

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not simply estimating gasoline demand directly. First, and most obviously, one may be interested in *how* income and price affect gasoline consumption, and not simply in the magnitude of the effect. The distributional or other consequences of improved fuel efficiency versus, say, reduced auto ownership might be of interest. Second, it is sometimes believed that disaggregate models have a higher level of parametric stability. This is due to the fact that disaggregation may often suggest new exogenous variables, which are important predictors in each component equation. Last, disaggregation may also be important if structural relationships exist among the endogenous variables.

The issue of what kind of structural model might underlie the joint demand for gasoline and transportation has yet to be discussed in the time-series literature on the subject. Existing models have simply assumed that the three demand components are determined simultaneously, and then have estimated the equations for each in reduced form. In fact, however, there is a growing body of microeconomic theory about durable goods and their usage, which is highly applicable to the question at hand. Consumer decisions about the type and number of vehicles to purchase (*AUTO*, *MPG*), and then about how much to use each vehicle (*DIST*), would seem to conform very well to a microeconomic model proposed originally by Heckman to analyze labor force participation and the decision about hours of work. The former is a discrete choice, and the latter is a continuous demand function *conditional* on the original discrete choice. Since Heckman's work, similar models have been applied to the housing market (choice of tenure and then housing consumption) by Lee and Trost (1978) and most recently to electricity consumption (choice of appliance and then power usage) by McFadden and Dubin (1982). In all of these cases, the consumer's decision about the choice of durable good and its usage is considered to occur simultaneously. Statistically, however, the usage equation is estimated conditional upon the choice of the good. This allows one to make statements about how the choice of good may structurally affect its usage.

Applying this model to transportation services, a household may be perceived as choosing first among a set of n alternative portfolios of automobiles. Each portfolio i is characterized by a set of attributes Z_i , which includes the number of vehicles and their fuel efficiency (*AUTO*, *MPG*). The probability of selecting portfolio i , P_i , will then depend on a vector of exogenous variables W (such as income, prices), parameters α , and the sets of attributes of the n portfolios Z_1, \dots, Z_n :

$$P_i = F_i(Z_1, \dots, Z_n, W, \alpha) \quad i = 1, \dots, n. \quad (3)$$

Given that a particular choice i has been made, there exists a conditional usage or driving demand equation, which will depend on the exogenous variables W and an error term ϵ . This may be represented in (4) below. Rather than estimating a set of n such conditional driving equations, the model may be simplified to estimate a single driving equation, but one in which the amount of driving depends on the attributes of the chosen portfolio. In this way *driving* still occurs conditional on the portfolio choice, but the conditioning is represented by using a single equation. This is shown in (5).

$$DIST = D_i(W, \epsilon) \quad i = 1, \dots, n \quad (4)$$

$$DIST = D(Z_i, W, \epsilon). \quad (5)$$

Although the choice of automobile portfolio and the decision about *DIST* occur at the same time, statistically it is a conditional demand equation that is estimated for *DIST*. This has raised considerable interest about whether the error term in (5) will be correlated with the Z_i . If, as seems likely in some situations, ϵ is correlated with the choice probabilities, then it will be correlated with the variables in Z , and OLS estimates of (5) will not be consistent. McFadden (1982) suggests applying a specification test to the Z variables in the usage equation, and if necessary, using either *FIML* to estimate the combined system (3)-(5) or instrumental variables on (5) alone.

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The macro characteristics of a country's automobile fleet as well as its aggregate vehicle usage may be thought of as the outcome of the individual decisions made according to (3)–(5). Although it is impossible to derive analytically the aggregate demand schedules, a heuristic argument suggests using a set of equations similar to (3)–(5) at the macro level. First, if the choice probabilities are aggregated across individuals, one would arrive at a countrywide frequency distribution over the set of automobile portfolios. The first moments of this distribution with respect to the variables *AUTO* and *MPG* will be expected values for countrywide auto ownership and average fleet fuel efficiency. These expected values will be functionally related not just to the mean values of *W* but to the full distribution of *W* in the population. Still, as is often done in demand studies, one might use as approximations equations containing only means of the vector of exogenous variables *W*. In a similar way, individual decisions about driving, in equation (5), can be aggregated to yield a macro driving equation. Although this equation would depend on much more than the country-average values of *Z* and *W*, an equation including only the latter could serve as an approximation. Thus, in the case where the portfolio characteristics *Z* are described by *AUTO* and *MPG*, a set of aggregate equations, such as (6)–(8) below, might be estimated:

$$DIST = D_1(AUTO, MPG, W, \epsilon_1) \quad (6)$$

$$AUTO = D_2(W, \epsilon_2) \quad (7)$$

$$MPG = D_3(W, \epsilon_3). \quad (8)$$

Since the aggregate equations are not analytically derived, one cannot say in advance whether the likely correlation between the error terms at the micro level will continue to exist in the aggregate equations. At this point, it is an empirical question, which should be resolved with a specification test (Hausman, 1978).

TABLE 1 Major Gasoline Demand Studies

	Pindyck (1979) ¹	Sweeney (1978) ²	Wildhorn <i>et al.</i> (1974) ²	CRA (1975) ³	DRI (1973) ²
<i>Gasoline Price Elasticity</i>					
Long-run total cons:	-2.07	-.78	-.78	-1.37	-.23
Driving:		} -.06	-.36		
Ownership:	-.64		-.25		
MPG:	1.43	.72	.17		
Short-run total cons:	-.37	-.22	-.26	-.28	-.07
Driving:		} -.22			
Ownership:	-.26				
MPG:	.11	.01			
<i>Income Elasticities</i>					
Long-run total cons:	.96	.82	.88	.06	.94
Driving:	.66	} .82			
Ownership:	.30		.88		
MPG:					
Short-run total cons:	.18		.18	.012	.28
Driving:	.06				
Ownership:	.12				
MPG:					

¹ Eleven Western countries, pooled 1955–1973 time series.

² U.S. National time series, 1950–1973.

³ 7-region pooled U.S. time series, 1950–1973.

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Although none of the existing time series studies of gasoline demand has applied this more structural model, those studies have produced an interesting set of reduced form income and price elasticities. For ease of comparison, these are summarized and presented in Table 1. In reviewing these studies, three conclusions seem to emerge.

- (1) With the exception of the CRA report, the studies are in general agreement in their estimates of long-run gasoline income elasticities. But they disagree about the long-run price elasticity of gasoline demand. The income effects are always slightly inelastic, while the price effects vary widely.
- (2) There is little agreement among the studies about how the income and price effects apply to each of the transportation components. The Wildhorn *et al.* research (1974) suggests that gasoline price exerts most of its influence through driving, while the Pindyck (1979) and Sweeney (1978) studies find it occurs mostly through fleet fuel efficiency. Wildhorn *et al.* find that income influences ownership most, while Pindyck concludes that income exerts its influence primarily on driving.
- (3) In most of the studies, the income and price effects are rarely *both* significant in the equation for any particular determinant of gasoline demand. If *MPG*, for example, has a strong price elasticity, then it has a weak income elasticity and *vice versa*. This suggests that the preembargo time series has a sufficiently strong common trend in the price and income data to make the separate estimation of each elasticity quite difficult. In a number of the studies, the equations for each component do not even include both income and price variables; one of the two variables is dropped from the equation, despite there being little theoretical justification for doing so. Estimates of one elasticity without the other variable being in the equation would have to be regarded quite cautiously.

3. Cross national data

■ In developing a cross national model, particular attention must be paid to the sources and reliability of data. Different countries may use different definitions or accounting systems, so that comparability can become a serious problem—at least in principle. To minimize these problems, the cross national data collected for this study used the same definitions and measurement standards as the U.S. time-series data. With these definitions, a full set of data was obtainable for 42 countries. The measurement of one variable, fleet fuel efficiency, was however, considered to be more reliable for 25 of these countries than for the others. For this reason, separate models were estimated for both the 25- and the 42-country samples. In all cases, the data were collected for the year 1972, the most recent period before the effects of the oil embargo.

The data on per capita income were obtained from annual World Bank Statistics and presented no problem. There has been, however, considerable recent discussion about the meaning of cross national income comparisons. Kravis (1978), in particular, has argued that the prices of many goods and services vary systematically among countries, and on the basis of a study of 16 nations, he has constructed a cross national GNP deflator. The problem with applying this deflator, however, is that the 16 countries researched by Kravis do not overlap with those used in many studies, including this one. To make the deflator available for more countries, Kravis has used a statistical analysis of the original 16-nation sample to estimate the deflator for over a hundred additional countries. In the 42-country sample used in this study, however, the simple correlation between this predicted deflator, and GNP per capita, is .98. Thus, it is doubtful that the index will add much to the equation, although it would still be instructive to estimate the model in both nominal and deflated dollars.

Ideally, the prices used in a gasoline demand model should include not only the price of gasoline but also the prices of the vehicles that use gasoline. In the case of gasoline prices, the U.S. Bureau of Mines conducts an annual survey of retail (pump) prices in

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75 countries. Developing a comparative price index for automobiles, however, is more difficult.

In the process of developing the GNP deflator, Kravis constructed an automobile price index. It appropriately considered, first, the average difference across countries in manufacturing prices, controlling for quality and variation in fleet mix, and second, differences across countries in automobile registration fees, excise taxes, and import duties. Unfortunately, this price index has not been extended beyond Kravis' original 16-nation sample.

To enable construction of a more simple auto price index that would apply to the 42-country sample used in this research, the Motor Vehicle Manufacturers Association provided a detailed survey of the taxes, fees, and import duties that apply to automobiles in each country. After adding the major fees, sales or V.A.T. taxes, and import duties, a price variable was constructed which represents the comparative cost to a consumer in each country of a world-traded automobile.

Unfortunately, such a price index is appropriate only for widely traded vehicles, and many countries assemble cars that are not traded. This is particularly true in the developing nations where there often exist licensed assembly plants. Such "local assemblies" are not taxed as imports, and they often constitute a large part of the vehicle fleet. It was simply beyond the scope of this research to do the extensive, primary source investigation necessary to determine the prices of such nontraded vehicles. As a consequence, the automobile price variable used here reflects only those differences between countries that are due to tax and import policy.

The consumption of gasoline in each country is available from the U.S. Bureau of Mines in the same publication as the data on gasoline prices. To match the data on gasoline, one would ideally want information on the stock of gasoline consuming vehicles. Current sources, however, record data in only two categories: all automobiles (including taxis), and buses and trucks. Since some automobiles may be diesel powered, while some trucks are gasoline powered, using either only the first category or the sum of the two categories may introduce a bias.¹

The final measurement issue is the most important—determining either fleet fuel efficiency or the number of miles driven by each vehicle. Using the identity (1), only one of these needs to be estimated, and two approaches are possible. First, one can obtain an independent estimate of vehicle miles driven from, for example, surveys or toll receipts. Dividing gasoline consumption per vehicle by this driving figure produces an estimate of actual fleet fuel efficiency. Second, an independent estimate of fleet fuel efficiency can be constructed by averaging data on the designed fuel consumption of different makes and models. Dividing fuel consumption per vehicle by this measure of fleet efficiency yields an estimate of miles driven per vehicle.

For this study, the fuel efficiency of the fleet in each country was estimated by applying the second of these two methods. To do this, data were first obtained on vehicle sales, by model, for as many years as possible. Unfortunately, the data for most countries are available in published form only back to 1970 (MVMA). Before then, the information for all but a few countries must be obtained directly from the manufacturers. Since the sales of automobiles between 1970 and 1972 constituted at least 40% of the fleet in most countries, the characteristics of these additions to the stock should be quite indicative of the 1972 stock as a whole. In the United States, for example, the estimated efficiency of the fleet went from 14.42 in 1962 to 13.57 in 1972. Using the vehicle age distribution, the average efficiency of the subpopulation of 1970–1972 vehicles in the United States would have been only 3% different from that of the fleet as a whole.

¹ It should be pointed out that the U.S. data on the vehicle fleet are also not differentiated by use of fuel, and the time-series studies have also had to use either all automobiles or all vehicles.

To estimate the fuel efficiency for each make or model of automobile sold, average city-driving EPA data for the years 1974 were obtained for each model of car sold in the United States (EPA). These figures were then increased by 10% to account for the lower fuel efficiency of the more recent American exhaust emission systems. Finally, a nonlinear regression equation was estimated relating these factored EPA figures to engine displacement ($R^2 = .89$), and this was used to predict the efficiency of automobile models not sold in the United States.

For 25 countries, very detailed data were available on the make and model of automobiles sold during the years 1970-1972. For these nations, weighting up the fuel efficiencies of each model produced a reasonable estimate for the efficiency of the fleet. In 17 additional countries, similar sales data were obtained, but not always by model—sometimes only by manufacturer. These less detailed data produced estimates for those countries which were not likely to be as accurate as the estimates for the 25-country sample.²

The issue of driving conditions raises a final consideration about whether the specification of the model should not include some geographic or other noneconomic variables that might influence transportation demand. Greene's cross state study (1979) suggests such factors could be important, although the theoretical arguments advanced often yield rather ambiguous hypotheses. For example, holding population constant, greater land area or lower population density certainly influences the distances people have to drive, if they choose to drive at all. If, however, they choose not to make as many trips, or to use other modes, then larger land area might not have any effect. Similarly, it is sometimes believed that auto ownership and vehicle characteristics are different in urban than in rural areas. Holding income and prices constant, should the level of urbanization increase vehicle ownership? Urbanization certainly increases trip making, but it also increases the opportunity for travel on public transportation. In short, it is hard to make rigorous theoretical arguments for such variables. To be as comprehensive as possible, though, the share of the population that lives in urban areas (*URBAN*) is included in the *AUTO* and *MPG* equations, while the land area of the country (*AREA*) is included in the driving equation.

In summary, the collection of available cross national data raises three issues, which can be addressed when estimating parameters of the model. First, any bias that might be introduced by the lack of information on the gasoline consuming fleet can be at least partially studied by estimating the equations using alternatively the automobile fleet and then the total vehicle fleet. Second, the model can be estimated in both nominal dollars and real dollars to test the importance of comparative prices and the usefulness of the Kravis deflator. Third, the model can also be estimated for two samples, which vary somewhat in the quality and level of detail with which the fleet efficiency variable was calculated. This will provide at least some indication about how sensitive the results are to the measurement of this important variable. The final data for the 25- and 42-nation samples are reported in Appendices A and B.

4. Statistical results

■ In estimating the cross national model, both a linear and a log-linear specification were tried, and a Box-Cox test was applied to choose between the two. The results of the procedure suggested that the log-linear form was superior for the overall consumption, vehicle ownership, and driving equations, but that the linear form was better for the *MPG* or fuel efficiency equation. In many respects, these results are consistent with *a priori*

² It should also be pointed out that although these procedures assume that "EPA city driving" characterizes operating conditions around the world (Owen, 1973), all of the existing estimates of fleet efficiency are based on the assumption of fixed operating conditions as well.

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expectations. As income per capita falls toward zero, for example, automobile ownership and driving must do likewise. Fuel efficiency, on the other hand, is at least somewhat technologically constrained. Thus the fuel efficiency equation should have a positive intercept, while the equations for driving and ownership need not. The statistical results merely reaffirm this intuition, and hence linear equations are reported for *MPG*, while log-linear forms are used for *AUTO* and *DIST*.

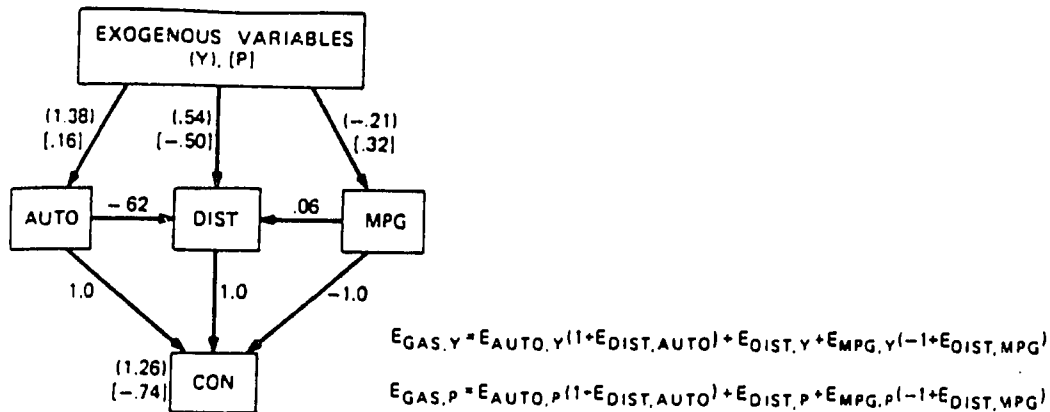
The first set of equations represents a sort of "base" model, in which the sample consists only of those 25 nations with the most reliable data. The equations in the "base" model are estimated by using only the automobile fleet and without deflating income or prices by the Kravis price index. This was the model in which the statistical specification issue was studied.

Answering the question of whether OLS is appropriate for estimating the driving equation involves testing whether possible correlation among the error terms in the three equations has created a correlation between the error term in the *DIST* equation and the variables *AUTO*, *MPG*. Assuming that some set of instruments exists which identifies the equations, a specification test can be applied by including *AUTO*, *MPG* and the residuals from their reduced-form equations in the *DIST* equation. If the residuals are significant, OLS assumptions are violated. In the case at hand, the price of automobiles (*TAX*) and the level of urbanization (*URBAN*) were assumed to be the identifying instruments for *AUTO* and *MPG*, while land area (*AREA*) entered only the driving equation. It is obvious that income and the price of gasoline should enter all of the equations. With this partitioning of the instruments, the results of the specification test were insignificant: the OLS assumptions were found to hold. Several alternative ways of assigning the three instruments (*TAX*, *URBAN*, *AREA*) were also tried, and in each case a resulting specification test also proved insignificant. It should be mentioned that the three instrumental variables actually have little explanatory power in the model. Income and gasoline prices totally dominate the equations. With such weak identifying instruments, the results of the specification tests should perhaps be regarded cautiously. On the other hand, without any additional variables, one can only conclude that OLS is justified, and hence it is the OLS results that are reported here.

In the first equation, that for automobile ownership, income is the only significant predictor, and it has a distinctly elastic effect. Neither the price of gasoline nor the opportunity price of imported automobiles (*TAX*) has any significant influence on the size of the automobile fleet. The level of urbanization is insignificant as well. In the second equation, that for fuel efficiency, there are more balanced income and price effects. When the *MPG* elasticities are computed at the sample mean values, that for income is $-.21$, while that for gasoline price is $.32$. Both of these are highly significant statistically. The negative income effect suggests that greater wealth does indeed lead to a demand for larger (less fuel efficient) automobiles. On the other hand, the price of automobiles, at least as measured by the opportunity cost of imports, exerts no influence on fleet fuel efficiency, and the level of urbanization is also insignificant. It is important to note at this point that the gasoline price elasticity of fuel efficiency is quite small in comparison with the estimates in the more recent time-series studies.

The results of the driving equation contain a number of interesting implications as well as some surprises. The first of these is that geographic land area plays no role in determining driving behavior—the equation is completely determined by economic variables and vehicle characteristics. Among the former, the income and price effects are significant statistically, although inelastic in magnitude. What are most interesting, perhaps, are the signs and magnitudes of the coefficients of the structural variables *MPG*, *AUTO*. Greater fuel efficiency seems to induce no additional driving, but greater auto

FIGURE 1
DECOMPOSITION OF DEMAND ELASTICITIES



ownership substantially reduces the use of each vehicle. Driving is indeed quite conditional upon at least the size of the automobile fleet.

The estimated system of three equations, for $LAUTO$, MPG , and $LDIST$, is depicted in Figure 1. Here all of the income and price elasticities are displayed, as well as the structural relationships among the endogenous variables. At the bottom of the figure are

TABLE 2 25-Country Sample, Undeclared, Automobile Fleet

Variable	Equation			
	$LAUTO^1$	MPG	$LDIST$	$LCON$
C	-13.2 (-8.60)	22.2 (7.67)	6.2 (3.70)	-2.11 (-1.98)
$PGAS$	.162 (.93)	.141 ² (6.28)	-.500 (-3.98)	-.700 (-4.81)
Y	1.375 (9.01)	-.00269 ³ (-6.24)	.537 (3.76)	1.22 (12.04)
TAX	.366 (1.31)	-.708 (-9.26)		.0501 (.289)
MPG			.063 (.384)	
$AUTO$			-.615 (-5.92)	
$URBAN$	-.581 (-1.45)	2.47 (.913)		-.452 (-1.64)
$AREA$			.0147 (.586)	.0482 (1.50)
R^2	.887	.821	.887	.938

¹ L represents a log-linear equation where parameters are elasticities. Other equations are linear. The t -statistics are in parentheses.

² Elasticity at mean sample values = .32.

³ Elasticity at mean sample values = -.21.

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the elasticity definitions showing how the component elasticities aggregate into the overall income and price elasticities of gasoline consumption. Summing these component effects, one obtains an overall income elasticity of 1.26, and an overall price elasticity of $-.74$. The final equation in Table 2 demonstrates that a simple reduced form gasoline demand equation produces almost identical aggregate elasticities (1.22 and $-.70$ respectively).

In summary, then, the base model yields four important conclusions. First, long-run gasoline demand is income elastic and only somewhat price inelastic. Second, almost all of the income effect occurs directly through its impact on automobile ownership. Third, the effect of gasoline price occurs exclusively through fuel efficiency and driving, with the latter effect being almost twice that of the former. Finally, auto ownership exerts a strong structural effect on driving, but fuel efficiency does not. Some implications of these results are discussed further in the next section. What is important here is to ascertain whether these conclusions are robust to different samples and variable definitions.

The first test of the model is to reestimate it using deflated income and prices. The results are reported in Table 3, and when compared with Table 2, there are no important differences. In the automobile equation, the income elasticity increases from 1.38 to 1.89, since deflating reduces the sample variation in "real" income. The price effects, however, remain insignificant. In the *MPG* equation, the coefficients change, because the equation is linear. The elasticities computed at the sample means remain essentially the same. In the *LDIST* equation, there is again no significant change, and the overall consumption

TABLE 3 25-Country Sample, Deflated, Automobile Fleet

Variable	Equation			
	<i>LAUTO</i> ¹	<i>MPG</i>	<i>LDIST</i>	<i>LCON</i>
<i>C</i>	-17.0 (-4.93)	23.3 (5.81)	6.91 (3.96)	-1.92 (-.86)
<i>PGAS</i>	.0252 (.128)	.0913 ² (4.86)	-.541 (-4.37)	-.801 (5.56)
<i>Y</i>	1.89 (5.36)	-.0019 ³ (-2.12)	.456 (2.41)	1.25 (5.34)
<i>TAX</i>	-.054 (-.242)	-.581 (-1.27)		-.148 (-1.03)
<i>MPG</i>			.103 (.240)	
<i>AUTO</i>			-.573 (-6.26)	
<i>URBAN</i>	-.54 (-1.21)	2.93 (.81)		-.37 (-1.24)
<i>AREA</i>			.71 (.30)	.04 (1.19)
<i>R</i> ²	.854	.702	.881	.932

¹ *L* represents a log-linear equation where parameters are elasticities. Other equations are linear. The *t*-statistics are in parentheses.

² Elasticity at sample means = .33.

³ Elasticity at sample means = $-.20$.

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equation exhibits very similar aggregate elasticities. Thus, whether nominal or "Kraus deflated" dollars are used seems to make almost no difference in the results of the model.

The second test is to examine the implications of using the fleet of automobiles as a proxy for the fleet of gasoline consuming vehicles. To do this, the model is reestimated using all vehicles (including trucks and buses). While this is only an approximation to the gasoline fleet, its bias is different from that introduced by using only automobiles. Since fuel efficiency data were available only for automobiles, the *MPG* equation remains the same, and automobile rather than total vehicle efficiency is used in the vehicle driving equation. The overall reduced-form gasoline equation is also the same, and so it is not reestimated either. In Table 4, then, the results for a vehicle (rather than automobile) ownership equation are presented, along with a structural equation for miles driven per vehicle. In all equations, the elasticities, significance levels, and R^2 values are extremely similar to those in Table 2. Since it makes little difference whether the model is estimated in terms of vehicles or automobiles, it would seem doubtful that an exact measurement of the gasoline-consuming fleet would change the results either.

The final test of the model involved estimating the base equations (those with the automobile fleet and undeflated income) for a larger sample of 42 nations. In addition to the countries in the original sample, this larger sample included primarily a number of poorer, less developed countries, for which the measurement of fleet fuel efficiency was not so precise. The results are in Table 5, and with only a few exceptions the coefficients are not significantly different from those of the base model. The main difference is that

TABLE 4 25-Country Sample, Total Vehicles, Undeflated

Variable	Equation	
	<i>LVEH</i> ¹	<i>LDIST</i>
<i>C</i>	-11.3 (-9.15)	6.37 (3.98)
<i>PGAS</i>	.099 (.674)	-.483 (-3.83)
<i>Y</i>	1.19 (9.89)	.525 (3.54)
<i>TAX</i>	.309 (1.27)	
<i>MPG</i>		-.017 (-.038)
<i>VEH</i>		-.578 (-4.69)
<i>URBAN</i>	-.27 (-.81)	
<i>AREA1</i>		-.0018 (-.068)
R^2	.882	.804

¹ *L* represents a log-linear equation where parameters are elasticities. Other equations are linear. The *t*-statistics are in parentheses.

TABLE 5 42-Country Sample, Undeclared, Automobile Fleet

Variable	Equation			
	<i>LAUTO</i> ¹	<i>MPG</i>	<i>LDIST</i>	<i>LCON</i>
<i>C</i>	-13.4 (-9.22)	21.9 (10.7)	8.47 (4.75)	-.391 (-.590)
<i>PGAS</i>	.132 (.627)	.122 ² (6.15)	-.547 (-3.89)	-.94 (-4.97)
<i>Y</i>	1.43 (9.6)	-.0023 ³ (-5.58)	.328 (2.38)	1.16 (9.9)
<i>TAX</i>	.114 (.34)	-.567 (-6.31)		-.369 (-1.47)
<i>MPG</i>			.057 (.158)	
<i>AUTO</i>			-.417 (-5.18)	
<i>URBAN</i>	-.22 (-.72)	3.8 (2.02)		.032 (.13)
<i>AREA</i>			-.518 (-2.05)	-.036 (-.93)
<i>R</i> ²	.914	.69	.742	.94

¹ *L* represents a log-linear equation where parameters are elasticities. Other equations are linear. The *t*-statistics are in parentheses.

² Elasticity at sample means = .26.

³ Elasticity at sample means = -.12.

the income elasticity of *MPG*, while still very significant, is about two-thirds of its value in the 25-nation sample. It is interesting that some of the geographic variables become significant for the first time in this larger sample, although this has no effect on the other coefficients.

As a consequence of these experiments, it does seem safe to assert that the data collected in this research contain a set of strong underlying relationships which continue to hold when the sample is substantially changed, when variable definitions are altered somewhat, and when the model is estimated with and without deflating by the only available world price index.

5. Conclusions

■ The results of the cross national model contain some important implications. first, for our understanding of the long-run structure of transportation and gasoline demand, and second, regarding the possible effectiveness of different regulatory policies designed to reduce the consumption of gasoline. Each of these issues is briefly discussed below.

□ **Gasoline and transportation demand.** The models estimated in the previous section give a consistent picture of gasoline demand, first, as being influenced exclusively by economic and not geographic factors, and second, as being more income than price elastic.

The income elasticity of overall consumption is always greater than unity, while the price elasticity is always less than one. The implications of this, for much of the developing world, are important. In the decade since the formation of OPEC, real per capita incomes in much of the Third World have risen by not that much less than the *real* rise in the price of oil. If the income elasticity of demand for gasoline is 1.2, while the price elasticity is -0.7 , and if these price/income trends were to continue, then it might be difficult for the Third World to reduce its per capita consumption of gasoline.

The strong effect of income on gasoline consumption occurs almost exclusively through its influence on the level of automobile ownership. Income may also influence the amount each vehicle is driven, but the concomitant increase in auto ownership cancels this by reducing vehicle usage. The sum of these two effects exactly offsets a small negative influence of income on fuel efficiency. Thus, for the rapidly developing nations to reduce their consumption of gasoline, it would seem important somehow to stem the rapid growth in auto ownership.

In contrast to the effect of income, the influence of price in the model is limited to improvements in fuel efficiency and reduced driving. Unlike the results in several time-series studies, gasoline prices are found to exert no influence on automobile ownership. The sum of the effects on fuel efficiency and driving, however, is still quite strong. Perhaps most importantly, the price effect through reduced driving is much greater than the price effect on fleet composition or fuel efficiency. The relatively small price elasticity of fuel efficiency and the higher one for driving again stand in sharp contrast to most of the recent time-series research.

The final point that deserves discussion concerns the lack of any effect on auto ownership or fuel efficiency from the price of vehicles. Since the $T\Delta X$ variable refers only to new vehicles, the results of the model imply that higher new car prices lead consumers to maintain their older cars longer. This conclusion is consistent with the Pindyck study, for example, where new car prices were found to decrease both new car sales and the rate of depreciation, by identical amounts. The sum of these two effects yields a steady-state size of the fleet that is invariant to prices of new cars.

□ **Regulatory effects.** It is tempting to consider the results of this research in light of current regulatory efforts, especially within the United States, to reduce gasoline consumption. Such extrapolation of the results, however, is probably not justified since the Energy Policy Conservation Act requires major shifts in technology, not simply the forced consumption of smaller cars. The cross national results suggest only that as gasoline prices rise, the shift to smaller cars is relatively modest. Similarly, given some exogenous shift to smaller cars, little additional driving in each car can be expected. How consumers respond to technological improvements in fuel efficiency, for cars of given size, could be another matter.

The major regulatory conclusion, which does emerge from the model, and might seem appropriate to the contemporary context, is the impact of possible reductions in automobile ownership. It is important to recall that the model, first of all, suggests that such reductions would be difficult to achieve by using price policy. Neither vehicle prices nor fuel prices seem to influence the size of the fleet. Assuming, however, that some policy could achieve reductions in the fleet, the cross national model says that this, in turn, would not be very effective in reducing fuel consumption. If the fleet, for example, were to be cut in half, the driving per vehicle would increase by almost 60%, leading to a reduction in the initial level of fuel consumption of only 20%. Such a policy might indeed involve a lot of effort and hardship, in exchange for a relatively modest reduction in fuel consumption.

Appendix A

■ Data for the 25-nation sample appear in Table A1.

TABLE A1 25-Country Sample

Country	AUTO ¹	MPG ²	DIST ³	PGAS ⁴	Y ⁵	TAX ⁶	PRICE ⁷
Argentina	.077	25.8	20.4	26	1053	2.11	.52
Australia	.356	25.4	15.4	26	2947	1.72	.88
Austria	.197	27.5	11.5	63	1922	1.18	.78
Brazil	.032	28.5	25.7	38	501	3.30	.45
Canada	.347	16.9	16.4	41	3884	1.27	.99
Denmark	.244	26.5	11.8	76	3159	1.18	.91
Finland	.177	28.5	23.0	71	2251	2.40	.74
France	.271	30.5	10.0	85	2775	1.33	.82
W. Germany	.268	27.5	10.1	80	3155	1.11	.86
Greece	.034	30.5	25.9	82	1134	1.05	.61
Ireland	.141	29.0	15.9	70	1326	1.35	.65
Italy	.232	31.5	8.4	102	1727	1.35	.73
Japan	.120	34.0	15.2	75	1980	1.24	.69
Mexico	.030	25.0	34.7	27	661	2.05	.54
Netherlands	.222	29.5	11.2	79	2429	1.34	.82
Portugal	.076	31.5	9.3	86	715	2.20	.55
Spain	.095	31.5	10.3	65	1089	1.81	.57
Sweden	.305	25.0	9.7	82	4109	1.21	.99
Switzerland	.256	28.0	14.2	72	3349	1.13	.92
U.K.	.235	27.5	10.7	69	2195	1.26	.73
U.S.A.	.472	14.8	13.6	40	4789	1.07	1.00
Uruguay	.052	29.0	16.8	69	927	2.98	.50
Venezuela	.075	20.5	28.6	17	1101	4.50	.56
Belgium	.229	28.5	10.5	82	2900	1.25	.89
S. Africa	.072	26.0	17.2	46	950	1.60	.58

¹ Autos per capita.

² Fleet fuel efficiency (miles per gallon).

³ Average miles per automobile (annual, in thousands).

⁴ Gasoline price (U.S. cents).

⁵ Income (dollars).

⁶ One plus local tax rates and import duty rates.

⁷ Kravis price index.

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Appendix B

■ Data for the 42-nation sample appear in Table A2.

TABLE A2 42-Country Sample

Country	AUTO ¹	MPG ²	DIST ³	PGAS ⁴	Y ⁵	TAX ⁶	PRICE ⁷
Ceylon	.007	29.0	12.3	65	117	1.50	.39
Dom. Repub.	.012	26.0	42.1	48	366	2.30	.46
El Salvador	.011	28.5	25.2	54	298	2.55	.43
Ethiopia	.0017	29.5	21.2	85	72	2.20	.38
Ghana	.006	29.5	38.3	43	257	1.61	.41
India	.0013	26.0	17.8	68	105	2.90	.34
Iran	.011	27.0	16.2	33	388	3.35	.41
Israel	.069	27.0	25.3	60	1919	1.55	.72
Jamaica	.052	26.0	17.6	39	768	2.02	.53
Kenya	.013	30.0	13.7	60	143	2.10	.41
Lebanon	.066	26.5	23.4	43	603	1.68	.52
Morocco	.016	30.0	13.3	75	224	2.20	.42
Norway	.22	27.0	10.6	85	2882	1.20	.88
Pakistan	.0025	31.0	23.5	47	175	2.95	.40
Paraguay	.0075	27.0	33.2	58	259	1.54	.42
Tunisia	.016	30.0	12.1	83	289	2.19	.43
Turkey	.0047	26.5	51.7	48	367	1.94	.42

¹ Autos per capita.

² Fleet fuel efficiency (miles per gallon).

³ Average miles per automobile (annual, in thousands).

⁴ Gasoline price (U.S. cents).

⁵ Income (dollars).

⁶ One plus local tax rates and import duty rates.

⁷ Kravis price index.

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On Elasticities in the RMA Transportation Model
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April 1991

Large portions of a country's energy consumption are used for transportation purposes. In order to forecast future energy demands with some degree of accuracy, and to simulate the effects of public policies on the demand for transportation energy, it is therefore important to understand what determines the demand for the various fuels. Elasticities measure the responsiveness of a variable such as the demand for gasoline to changes in policy variables such as income and prices. The price elasticity of demand, for example, is defined as the ratio of the percentage change in the quantity demanded to a percentage change in the price. Elasticities are usually estimated from historic data by running time series regressions. Assuming that consumers' preferences are not changing significantly over time, the estimated elasticity values can then be used in forecast models or simulation models to predict future quantities and to evaluate available policy options.

A great number of models have been developed to estimate the demand for gasoline and the various elasticities for the United States and some Western European countries. Two approaches are commonly found in the literature. A straightforward approach observes that the demand for each of the fuel types is just a function of the real price of that fuel (P_t), real per capita income (Y) and the population (POP)

$$FUEL_t = f(P_{ft}, Y_t, POP_t) \quad (1)$$

Equation (2) is usually estimated by ordinary least squares (OLS) on a log linear regression function of the kind:

$$\log(FUEL_t) = a + b1 \cdot \log(P_{ft}) + b2 \cdot \log(Y_t) + b3 \cdot \log(POP_t) + e_t \quad (2)$$

The results of this regression can directly be interpreted as the price elasticity of the demand for fuel type i ($b1$), and the income elasticity of that fuel type ($b2$). Various studies run alternative regressions that include additional variables without adding explanatory power or improving the goodness to fit. Other functional forms are also tested but do not tend to outperform the specification of equation (3). Results from some of the studies done for the demand of gasoline using this approach are listed in table 1.

Table 1

Study		E _{GASOLINE,Y}		E _{GASOLINE,P}	
		LR	SR	LR	SR
Dahl		1.17	0.12	-0.2	-0.98
Baltagi, Griffin	US _{ols}	0.89		-0.9	
	US _{gls}	0.55		-0.61	
Drollas	UK	1.29		-0.55	-0.28
	FRG	1.15		-0.82	-0.45
	F	1.08		-0.58	-0.44
	AU	1.02		-0.82	-0.52
	US	0.34		-0.73	-0.35
Rice, Frater	UK	0.71		-0.18	-0.99

An alternative approach looks at the components of fuel demand, namely the vehicle stock, the average annual vehicle usage, and the efficiency of the vehicle fleet. All of the models are based on the identity:

$$FUEL_{it} = VEH_{it} * DIST_{it} * LKM_{it} \quad (3)$$

where $FUEL_{it}$ = consumption of fuel i in year t
 $DIST_{it}$ = average annual vehicles usage in km by fuel type i in year t
 VEH_{it} = vehicle stock using fuel type i in t
 LKM_{it} = efficiency (liters per 100 km or kilowatt hours)

This approach estimates each of the components separately and uses the relationship displayed in equation (3) to calculate fuel demands. Given the log linear form of the relationship of equation (3), income and price elasticities can be found by realizing that they are the sum of the three separate component elasticities

$$\begin{aligned} E_{FUEL,P} &= E_{VEH,P} + E_{DIST,P} + E_{LKM,P} \\ E_{FUEL,Y} &= E_{VEH,Y} + E_{DIST,Y} + E_{LKM,Y} \end{aligned} \quad (4)$$

Results from these kind of studies for the demand for gasoline are listed in table 2.

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Table 2

Study	E _{GASOLINE, Y}				E _{GASOLINE, F}			
	TOTAL	DIST	LKM	VEH	TOTAL	DIST	LKM	VEH
Wildhorn	0.88	0	0	0.88	-0.78	-0.36	0.17	-0.25
Sweeney	0.82	0.82	0	0	-0.78	-0.06	0.72	0
Pindyck	0.96	0.66	0	0.30	-2.07	0	1.43	-0.64
Wheaton	1.26	0.54	-0.21	1.38	-0.74	-0.5	0.32	0.16
Gately	cars		0.92		-0.07	0.01		
	trucks		1.16		-0.04	0.01		

Elasticity values are needed to incorporate the effect of price and/or income changes on the demand for the various fuel types into the RMA transportation model. The RMA transportation model is a very disaggregate model with the individual's trip-making as the choice variable. Since the relationship between the number of trips taken by an individual and the number of vehicles per capita is very stable, trip-making can be viewed as a good proxy for the vehicle stock. Individuals decide on the number of trips to take, the average length of the trips and the mode by which the trips are made based on their economic well-being. To create a base case for 1989 for Romania or Czechoslovakia, data and/or educated assumptions are used on these variables as well as on the fuel shares of the various modes of transportation, the fuel efficiencies and the load factors of the different modes.

Changes in income or in the price of the fuels affect these variables but to a varying degree. We will assume that the variable that is most directly affected by price and income changes is the number of trips that an individual is taking. Fuel shares by mode are not affected because each of the different modes of transportation is run exclusively on one type of fuel so that no fuel shift should be expected. Load factors might change, but the responses are not likely to be large nor are they easily predictable with our present knowledge. Once more data become available, the responsiveness to income or price changes should be analyzed more thoroughly. Modal shares, on the other hand, have changed considerably in most countries as per capita income rises. While both public and private trip making are likely to increase with income, private travel usually increases more rapidly. This phenomenon is represented in the model by larger income elasticities for private travel than for public travel modes. The response of fuel efficiency to price and income changes has been studied and is used in the model.

How then do price and income changes affect the number of trips that an individual is going to make? The elasticity of trip-making can be estimated by using the relationships in equation (4). It should be kept in mind that trip-making here is used as a proxy

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for the vehicle stock. ¹

$$\begin{aligned} E_{\text{TRIPS},P} &= E_{\text{GASOLINE},P} - E_{\text{LKM},P} - E_{\text{DIST},P} \\ E_{\text{TRIPS},Y} &= E_{\text{GASOLINE},Y} - E_{\text{LKM},Y} - E_{\text{DIST},Y} \end{aligned}$$

We are initially assuming that $E_{\text{DIST},Y} = 0$ and $E_{\text{DIST},P} = 0$, i.e. that the average annual distance travelled is not affected by changes in the price or changes in income since this effect has been shown to be rather small. Ideally we can use the results from table 1 and 2 to make reasonable assumptions about the elasticity of trip-making since the component elasticities have been estimated and can be found in the literature. The estimated elasticities are based on data from the United States or from some Western European countries. Looking at the tables, we observe an enormous variation in the estimated elasticity values, especially with respect to the price elasticities found in the various publications. What values should be used in the RMA transportation model?

For the income elasticity of trip making we assumed a value of 1.0. There are a number of reasons for this choice. More recent studies have shown that the income responses have been significantly larger in the European countries than in the U.S. Drollas argues that this shows a different attitude towards cars. Americans consider the car more of a necessity than Europeans. Suburban living and lack of alternative ways of transportation result in less responsiveness to income changes. Furthermore, it has been shown that a large part of the income effect comes through an increased vehicle stock, an effect which is most likely going to be stronger in a country like Romania where car-ownership is still very low and where the demand in the past may have been suppressed largely due to limited supplies. This should translate directly into an increased number of trips taken.

For the price elasticity, we assumed a value of -0.1, which is at the lower end of the scale. Given that income is still relatively low in Romania, vehicles are rather large investments. It is probably save to assume that vehicle owners are among the higher income groups. Once the money is spent on a vehicle, price changes are probably not going to affect the actual use significantly.

¹ Since in Czechoslovakia and in Romania the number of trips by automobile were not known, initial estimates were derived by taking the overall quantity of a fuel used in transportation and dividing it by the fuel efficiency, the average trip length and the population. For gasoline the equation is

$$\text{GAS/LKM/DIST/POP} = \text{TRIPS (per person)}$$

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